# EFFECT OF CLASS C PULVERIZED FUEL ASH ON SHEAR STRENGTH OF SILTY SAND SOIL TYPE

SITI KHADIJAH BINTI SAIFUL BAHARI

CIVIL ENGINEERING

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by

Siti Khadijah Binti Saiful Bahari

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the requirement for the
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**Universiti Teknologi PETRONAS**
**Bandar Seri Iskandar**
**31750 Tronoh**
**Perak Darul Ridzuan**

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# CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

Syed Baharom

(Dr. Syed Baharom Azahar Syed Osman)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2008

# CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the orginal work contained herein have not been undertaken or done by unspecified sources or persons.

**SITI KHADIJAH BINTI SAIFUL BAHARI**

# ABSTRACT

The potential usage of PFA in soil stabilization has increased significantly due to increased availability and the introduction of new environmental regulations that encourage the use of PFA in geotechnical applications when it is environmentally safe. The main objective for this project is to investigate the benefit of using PFA for soil stabilization. This study covers the basic characteristics of soil and PFA, compaction, shear strength parameters and Atterberg limit. The samples were subjected to unconfined compression tested immediately as compacted and after curing for 3 and 7days at temperature of $38^0$C to develop water content-strength relationship. This soil was mixed with different percentages of PFA varying from 9% to 24% with increment of 3% by dry weight of soil. Soil samples were collected from oil-palm plantation at Changkat Cermin while PFA were collected from TNB Manjong. The soil sample was predominantly quartz while the PFA is classified as Class C PFA. The mixtures between soil and PFA had increased the compaction and shear strength behavior. The optimum dry density was achieved when PFA content was 12%. Shear strength of the soil-PFA mixtures were increased 50% during immediate test and the greatest shear strength acquired was during 7 days of curing with PFA content of 21%. During the experiments all samples failed with visible shear failure with angle of 60-65$^o$ and all samples became more brittle after curing. The particles sizes of soil-PFA mixtures became more solid and contain lesser air voids compared to the untreated soil. The bonding between these materials indicated chemical reactions had occurred in these materials to form cementation product. From the experiments conducted, it can be concluded that the addition of Class C PFA has improved the engineering properties of soft soil significantly.

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# CHAPTER 1
# INTRODUCTION

## 1.1 Background Study

Pulverized Fuel Ash (PFA) is a by-product from coal-fired power station. PFA is a fine-grained, powdery particulate material that is carried off in the flue gas and usually collected from the flue gas (electrostatic precipitators, bag houses, or mechanical collection devices such as cyclones). In general, there are three types of coal-fired boiler furnaces used in the electric utility industry. They are referred to as dry-bottom boilers, wet-bottom boilers, and cyclone furnaces. The most common type of coal burning furnace is the dry-bottom furnace.

A general flow diagram of PFA production in a dry-bottom coal-fired utility boiler shows in Figure 1.1 below:-

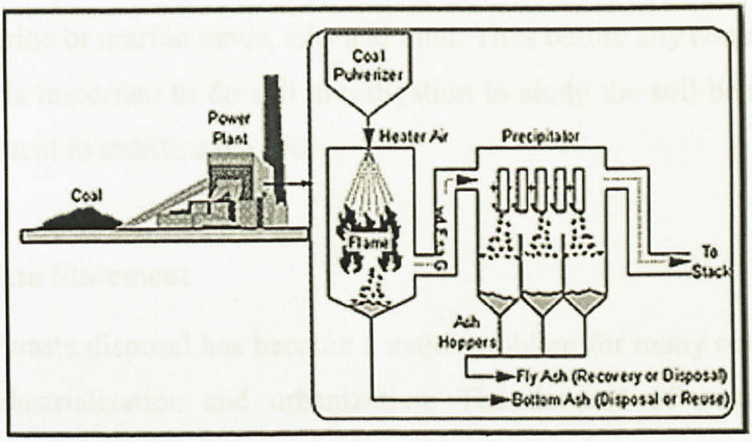


**Figure 1.1: Typical layout of dry bottom coal fired power plant (source from FHWA)**

According to Malaysia's Ninth Plan, the consumption of coal for power generation and industrial use is expected to reach 19.0 million tones and 2.2 million tones, respectively, in 2010, due mainly to the commissioning of two new coal-based generation plants in Peninsular Malaysia (Tanjung Bin, Johor and Jimah, Negeri Sembilan). These plants will utilize electrostatic precipitators and flue gas de-sulphurisation process to meet environmental standards. These new plants will produce large amount of by product from coal thus we need to utilize the usage of

PFA. In well-developed countries, utilization of PFA especially in soil stabilization has been introduced for many years. The potential use of PFA in soil stabilization has increased significantly due to increased availability and the introduction of new environmental regulations that encourage use of PFA in geotechnical applications when it is environmentally safe.

Soil is one of the most abundant and cheapest construction materials. Even so its use can be greatly extended by enhancing its engineering performance, for example by the addition of cementations materials or soil stabilization. Most civil engineering operations are carried out in soil and obviously poor soil conditions will be encountered on some construction sites. If such soil cannot be removed, then its engineering behavior can often be enhanced by some method of ground treatment. Bell (1993) stated that poor soil conditions usually are attributed to an excess of groundwater or a lack of strength and associated deformability. Besides that, lack of strength leads to soil failing if it is overloaded. Some of the most problematic soils include peat and organic soils, quick clay, residual montmorillonitic clays and varied clays, which may be sensitive to extra sensitive and loosely packed saturated alluvial, estuarine or marine sands, silts and mud. Thus before any construction done on the site it is important to do soil investigation to study the soil behavior and do any soil treatment to stabilize the soil.

## 1.2 Problem Statement

Solid waste disposal has become a major problem for many countries due to the rapid industrialization and urbanization. The demand of power is mostly supplied by thermal power plants where coal is used and a large quantity of PFA produced from the process. PFA is kept by various collection devices to prevent it from entering atmosphere.

PFA creates different environmental problems like ash dust, leaching from coal ash land applications, skin contact with ash and radioactivity of coal ash. Transforming this waste material into a suitable construction material may minimize the cost of its disposal and in alleviating environmental problems. PFA has become an attractive construction material because it has physical and chemical properties that are useful for construction and industrial materials. It is currently used in roadbeds, structural fill, cement, concrete and flowable fill for waste stabilization and cementing agent in soil stabilization (EPRI, 1998).

Soft soils challenge geotechnical engineers because of their high compressibility and low undrained shear strength. Soft soils deposits often have highly varied geological histories, thus making their stress-strain behavior complex (Don J. DeGroot, 2001).

Therefore, this project presents a study on the use of PFA to stabilize the soft soils to improve their engineering performance.

### 1.3 Objective and Scope of Study

Basically the main objective of this study is:-

- To study the impact of using PFA on shear strength of soft soil and the correct mix proportion of using PFA to stabilize soil.

The scope of this research project is to use different percentages of PFA in soft soil with varying water content and to look at the effect of changes with respect to compaction, shear strength and Atterberg limit.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Pulverized Fuel Ash

Sear (2001) stated that coal is a readily available source of energy consisting of carbon, volatile organic materials and a mixture of various minerals (shales, clays, sulphides and carbonates). Coal, a mineral substance of fossil origin may be one of four main types: -

- Anthracite (more than 90% carbon)
- Bituminous or hard coal (~80% carbon)
- Lignite and brown coal (<70% carbon)

American Society for Testing and Materials (ASTM) classified PFA into 3 classes:-

- Class F – pozzolanic fly ash normally produced from burning anthracite or bituminous coal.
- Class C - pozzolanic and cementations fly ash normally produced from the burning of sub bituminous coal and lignite.
- Class N – raw or calcined natural pozzolans such as diatomaceous earths, opaline cherts and shales, tuff, volcanic ashes and pumicites and calcined clays and shales.

Because of variations in coal from different sources, as well as differences in the design of coal-fired boilers, not all PFA the same. Mackiewicz (2005) described that bituminous coal has low concentrations of calcium compounds and the ash produced Class F PFA exhibits no self-cementing characteristics. The addition of activators such as lime yields cementations products so that this material can be used for a wide range of soil stabilization applications. Subbituminous coals have higher concentrations of calcium carbonate ($CaCO_3$), thus the ash produced Class C PFA during combustion is rich in calcium, resulting in the self-cementing characteristics.

### 2.1.1 Physical Properties of PFA

PFA consists of fine, powdery particles that are predominantly spherical in shape, either solid or hollow, and mostly glassy (amorphous) in nature as shown in Figure 2.1 below. The carbonaceous material in PFA is composed of angular particles. The color of PFA can vary from tan to gray to black, depending on the amount of unburned carbon in the ash. The lighter the color of PFA, the lower the carbon content. Lignite or subbituminous PFA are usually light tan to buff in color, indicating relatively low amounts of carbon as well as the presence of some lime or calcium. Bituminous PFA are usually of some shade of gray, with the lighter shades of gray generally indicating a higher quality of ash (FHWA, 2003).

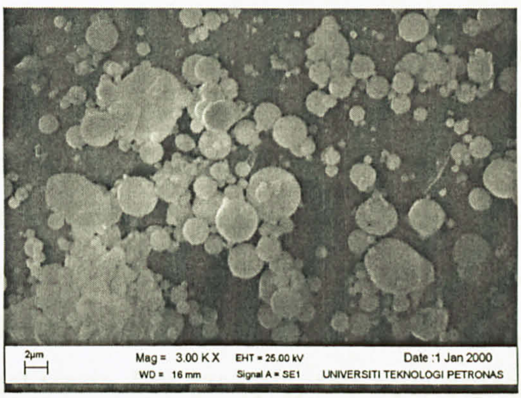


**Figure 2.1: PFA that consist of spherical glassy particles**

### 2.1.2 Chemical Properties of PFA

PFA consists primarily of oxides of silicon, aluminum iron and calcium. Magnesium, potassium, sodium, titanium, and sulfur are also present to a lesser degree. The chemical properties of PFA are influenced to a great extent by those of the coal burned and the techniques used for handling and storage. There are basically four types, or ranks, of coal, each of which varies in terms of its heating value, its chemical composition, ash content, and geological origin.

The difference between Class F and Class C PFA is in the amount of calcium and the silica, alumina, and iron content in the ash. In Class F PFA, total calcium typically ranges from 1 to 12 percent, mostly in the form of calcium hydroxide, calcium sulfate, and glassy components in combination with silica and alumina. In contrast, Class C PFA may have reported calcium oxide contents as high as 30 to 40 percent. Another difference between Class F and Class C is that the amount of alkalis (combined sodium and potassium) and sulfates ($SO_4$) are generally higher in the Class C PFA than in the Class F PFA (FHWA, 2003).

## 2.2 Soft Soil

Amaryan (1993) explained that soft soils are highly problematic because of the susceptibility of these soils to undergo large changes in volume due to fluctuations in the moisture content. In monsoon seasons, soils imbibe water, swell, become soft and capacity to bear water is reduced. In drier seasons, these soils shrink or reduce in volume due to evaporation of water and they become harder.

Soil, with the exception of peat is formed by the breakdown of rock masses either by weathering or erosion. Many soils can prove to be problematic in geotechnical engineering because they expand, collapse, disperse, undergo excessive settlement, have a distinct lack of strength or are corrosive. There are many types of problematic soils, some of the most noteworthy being swelling/shrinking clay, collapsible soils, quick sands, frozen soils and peat. Most of these problematic soils are young in geological terms. For example, soft soils deposited on the margins of some of the large rivers in Ireland are a combination of silts, organic silts or silty peats which have properties that depend on the relatively recent geological and hydrological history of the location. The consequences that may attributable to the behavior of such problem soils can result in considerable financial loss.

Another factor that must be taken into account is the weathering process because it not only reduces the strength of clay soils but it also facilitates the development of fissures. Higher moisture contents are found in the more weathered clay. Weathering of clay soils leads to a loss of strength, reduction of deformation moduli and increase in plasticity. Fissuring also increases, which reduces mass strength (Bell and Culshaw, 2001).

## 2.3 Some types of soil stabilization

Sear (2001) pointed out that the soil stabilization is defined as the treatment of a material to improve its strength and other physical properties. Many stabilization techniques rely on reducing the water content of the in situ soil and increasing the strength and stability. The latter may be provided by a pozzolanic reaction between lime and siliceous material e.g. clay.

Bell (1993) explained that the objectives of mixing additives with soil are to improve volume stability, strength and stress-strain properties, permeability and durability. The development of high strength and stiffness is achieved by reduction of void space, by bonding particles and aggregate together, by maintenance of flocculent structures, and by prevention of swelling. The permeability is altered by modification of pore size and distribution. Good mixing of stabilizers with soil is the most important factor affecting the quality of result. The two most commonly used stabilizers are cement and lime.

### 2.3.1 Cement stabilization

Bell (1993) pointed out that the addition of small amounts of cement, up to 2%, modify the properties of a soil, while large quantities can cause radical changes in these properties. Any type of cement may be used for soil stabilization but ordinary Portland cement is mostly wide used. Rapid-hardening cement with extra calcium is used in organic soils, retarded cement will tolerate construction delay and sulphate-resisting cements are rarely suitable. The characteristics when using cement-stabilized for soils are:-

- With increasing cement content the shear and bearing capacity increase, as does the durability to wet-dry cycles.
- Permeability decreases but tend to increase in clayey soils.
- Swell ability of clay soils is reduced.
- The strength of soil-cement tends to increase in linear manner with increasing cement content but different soil it increase at different rates.

The principal use of soil-cement is as base material underlying pavements because it helps to prevent pumping of fine-grained sub-grade soils into the pavement above. Soil-cement is also used for afford slope protection to embankment dams, provided slope protection for canals, river bank, spillways, highways and coastal cliff. In addition to water storage reservoirs, soil-cement has been used to line waste-water treatment lagoons, sludge-drying beds, ash settling ponds and sanitary landfills. It also has been used as massive fill replacement to provide uniform support to foundations where inadequate bearing capacity was available (Bell, 1993).

### 2.3.2 Lime stabilization

Bell (1993) say that lime stabilization refers to the stabilization of soil by the addition of burned limestone products, either calcium oxide (i.e. quicklime, $CaO$) or calcium hydroxide, $Ca(OH)_2$. On the whole, quicklime is often used to stabilize soft, clayey soils. This reaction of quicklime and water produces hydrated lime and heat. This process helps with drying the soil and when the treated material compacted, forms a firm working platform for following construction.

Ingles and Metcalf (1972) suggested that the addition of up to 3% of lime would modify silty clay, heavy clay and very heavy clay, while 3%-4% was required for the stabilization of silty clay and 3%-8% was proposed for stabilization of heavy clay and very heavy clay. They further suggested that a useful guide is to allow 1% of lime (by weight of dry soil) for each 10% of clay in the soil. The characteristic gained after using soil-lime for stabilized soils are: -

- The plasticity is reduced as in the potential for volume change. For example, test carried out by US Bureau of Reclamation indicated that the addition of 4% lime reduced the plasticity index of clay from 47% to 12%.
- Increases the optimum moisture content and reduces the maximum dry density for the same compactive effort. The significance of these changes upon the amount of lime added and the amount of clay minerals present.
- Soil mixed with low lime content attains a maximum strength in less time compare which higher content of lime. Thus, strength does not increase

linearly with lime content and in fact excessive addition of lime reduces strength.

The principal use of soil-lime is for subgrade and subbase stabilization and as a construction expedient on wet sites where lime is used to dry out soil. Soil-lime mixtures should be compacted to high density in order to develop maximum strength and stability. This required compacting at or near the optimum moisture content. It is also used in embankment construction for roads, railways, earth dams and levees to enhance the shear strength of the soil. Lime stabilization of clay soils, especially expansive clay soils can minimize the amount of shrinkage and swelling they undergo. Hence, such treatment can be used to reduce the number and size of cracks developed by building founded on suspect clay soils (Bell, 1993).

### 2.3.3 Pulverized Fuel Ash in Soil Improvement

Soil density, water content, plasticity, and strength performance of soils are the engineering properties most often altered. PFA provides the following benefits when used to improve soil conditions: -

- Eliminates need for expensive borrow materials.
- Expedites construction by improving excessively wet or unstable subgrade.
- By improving subgrade conditions, it promotes cost savings through reduction in the required pavement thickness.
- Can reduce or eliminate the need for more expensive natural aggregates in the pavement cross-section.

Prabakar et. al (2004) concluded that addition of PFA reduces the dry density of soil due to the low specific gravity and unit weight of the soil by 15-20%. At the same time, by adding PFA up to 46%, the void ratios of the soils can be increased by 25% and improve the shear strength of PFA mixed with soil. Senol (2002) in his research also concluded that the maximum dry density decreases and optimum water content increases as PFA content increases from 12%-20%. The addition of PFA increases the maximum strength significantly. He also indicated that Class C PFA can be used without any other activator.

Mackiewicz (2005) measured that most PFA stabilization applications require PFA content ranging from 12% to 15% (dry weight basis), where as cement or lime stabilization typically requires content ranging from 3% to 7%. Even with the addition of larger quantities of ash to achieve the stabilization required, the PFA treatment is generally economically then the lime and cement alternatives. Typical PFA addition rates are 8 percent to 16 percent based on dry weight of soil in order to improve soil strength. The addition rate depends on the nature of the soil, the characteristics of the PFA and the strength desired (FHWA, 2003).

PFA that is produced from the burning of lignite or subbituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties (ability to harden and gain strength in the presence of water alone). Pozzolans are siliceous or aluminous materials, which in a finely divided form and in the presence of water, react with calcium hydroxide at ordinary temperatures to produce cementations compounds (FHWA, 2003). Class F PFA has little or no cementations value while Class C PFA is usually contain significant amount of lime along with pozzolanic material. Formation of cementations material by reaction of lime with the pozzolans ($AlO_3$, $SiO_2$ and $Fe_2O_3$) in the presense of water is known as hydration of PFA. The hydrated calcium silicate gel or calcium aluminate gel (cementations material) can bind inert material together (Senol, 2002). The pozzolanic reactions for soil stabilization are as follows: -

$$CaO + H_2O \rightarrow Ca(OH)_2$$

$$Ca(OH)_2 \rightarrow Ca^{++} + 2[OH]^-$$

$$Ca^{++} + 2[OH]^- + \underset{\text{(silica)}}{SiO_2} \rightarrow \underset{\text{(gel)}}{CSH}$$

$$Ca^{++} + 2[OH]^- + \underset{\text{(alumina)}}{Al_2O_3} \rightarrow \underset{\text{(gel)}}{CAH}$$

# CHAPTER 3
# METHODOLOGY

200kg PFA was obtained from coal-fired TNB Manjung Power Plant for this project and were stored into air-tight special container. Soil samples were collected from oil-palm plantation under Ladang Perbadanan FIMA Berhad located in Changkat Cermin. The soil was excavated using backhoe, transported and stored at the Geotechnical laboratory in a special container to maintain the moisture content. This laboratory works for this research were mainly divided into two main parts: -

i. basic engineering physical properties of PFA and soft soil

ii. test on soil samples mixed with PFA

The tests conducted on soil samples mixed with different percentage of PFA ranging from 9% to 24% with increment of 3%. For all experiment done, the soft soil were oven-dried for 24hours with temperature of $110 \pm 5^0$C, then crushed and grinded into smaller particles before sieved into desired particles size according to specific testing while the PFA are sieved into particles size of 425µm.

## 3.1 Basic engineering physical properties of PFA and soft soil

### 3.1.1 Moisture Content Test

Moisture content which is also referred to as water content is a relationship between air, water and soil. The objective of this testing is to determine the water content in the soil where the reduction in mass by drying is due to loss of water. The soil is over-drying for 24hours with temperature 100°C ± 5°C. The moisture content is calculated as mass of the water over mass of the dry soil. The moisture content influences soil consistency and strength and the energy with which moisture is held influences their volume change characteristic. Moisture content test was carried out according to ASTM D2216 – Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil Rock and Soil-Aggregate Mixtures and calculated based on the following equation: -

$$w = \frac{M_{CMS} - M_{CDS}}{M_{CDS} - M_{SC}} \times 100\%$$

where $M_{CMS}$ is Mass of container with moist soil

$M_{CDS}$ is mass of container with dry soil

$M_{SC}$ is mass of container

### 3.1.2 Particles Size Distribution

Two methods are generally used to find the particle size distributions of soil are:-

- Dry Sieve Analysis – for particle more than 0.075mm in diameter
- Hydrometer Analysis - for particle smaller than 0.075mm in diameter

The soil was oven-dried for 24hours at temperature 110±5oC and break into small particles before it was sieved. Nine sieves from opening diameter 0.063mm until 2mm including pan were used and the weight of each sieve as well as pan is recorded. The soil is poured into the top sieve and placed in the mechanical shaker for 10minutes. Hydrometer test will be carried out by taking the soil retained on the bottom pan. Dispersing agent (sodium hexametaphosphate) was added to the soil sample and poured into cylinder and added distilled water until 1000ml. This testing is using ASTM 151H type of hydrometer. Combined sieving and sedimentation procedures enable a continuous particle size distribution curve of a soil to be plotted from the size of the coarsest particle down to the clay size. This testing is done using ASTM D422 – Standard Test Method for Particle-Size Analysis of Soils.

### 3.1.3 Specific Gravity Test

Specific Gravity is defined as the ratio of the unit weight of soil to the unit weight of water. The specific gravity of soils if often needed for various calculations in soil mechanics. Three methods to determine specific gravity in laboratory are:-

- Gas Jar method – suitable for most soils including those containing gravel size particles

- Small pycnometer— suitable for soil consisting of clay silt and sand sized particles
- Large pycnometer-- suitable for soil containing particles up to medium gravel size

Specific Gravity test was determined by taking an amount of dry soil sample, placed into the pycnometer and weighted. Then the pycnometer was added with water until it full and ensure that no entrapped water. After topping-up with water, the pycnometer was leaved for 24hours for the sample to settle and weighted again. Finally, the pycnometer was emptied and cleaned, then filled with water and weighted again. It has been carried out according to ASTM D854 – Standard Test for Specific Gravity Soil Solids by Water Pycnometer and calculated based on the following equation:-

$$\text{Particles density, } \rho s = \frac{\text{Mass of soil } (m_2 - m_1)}{\text{Volume of soil particles } (m_4 - m_1) - (m_3 - m_2)}$$

where $m_1$ is mass of pycnometer with plate

$m_2$ is mass of pycnometer with plate and soil

$m_3$ is mass of pycnometer with plate, soil and water

$m_4$ is mass of pycnometer with plate and water

### 3.1.4 Atterberg Limit

The Swedish soil scientist Albert Atterberg originally defined seven "limits of consistency" to classify fine-grained soils, but in current engineering practice only two of the limits, the liquid and plastic limits, are commonly used. The Atterberg limits are based on the moisture content of the soil and used to classify a fine-grained soil according to the Unified Soil Classification system or AASHTO system.

The plastic limit (PL) is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state. Approximately 20g samples that passed 425μm sieve were mixed with distilled water and molded in the hand until it dried sufficiently for slight cracks to appear. The sample then divided into tow portion of ±10g and each of these divided into four sub-samples. One of the sub-samples was rolled into a ball and then rolled on a glass plate into thread of 3mm in diameter until it starts to crumble. The same procedure is followed with other sub-samples and average of water content is reported as plastic limit. The plastic limit test was performed according to ASTM D-4318 Standard Test Method for Plastic Limit of Soils.

The liquid limit (LL) is the moisture content that defines where the soil changes from a plastic to a viscous fluid state, at which a part of soil in a standard liquid limit apparatus. Test specimen that passed 425μm sieve was mixed thoroughly with distilled water and stored in an air-tight container for 24hours to allow full penetration of the water. Then the specimen was remixed and a portion of it placed into brass cup without entrapped air bubbles and the surface was level to the top of the cup. The cup was placed onto the base of the cone penetrometer stand and 80g of standard cone was lowered so it just touched the surface of sample paste. After that the cone was released to penetrate for five seconds and relocked in its new position, took the reading and repeated for second reading. The difference between first and second readings gives the amount of cone penetration. The test was repeated with varying moisture content to determine the fall cone penetration. From graph of cone penetration versus water content, liquid limit of the sample taken as the water content corresponding to a penetration of 20mm. The liquid limit was performed according to BS-1377 Standard Test Method for Liquid Limit of Soils by Using Fall Cone Method.

### 3.2 Test on soil samples mixed with PFA

#### 3.2.1 Compaction Test

Das (2002) stated that compaction is the densification of soil by removal of air, which requires mechanical energy. The degree of compaction of a soil is measured in terms of its dry unit weight. Soil compaction increases soil strength (the ability of soil to resist being moved by an applied force), also changes pore space size, distribution, and soil strength.

This test covers the determination of the dry density of soil 2mm test sieve when it is compacted in a specified manner over a range of moisture contents. The range includes the optimum moisture content at which the maximum dry density for this compaction is obtained. This experiment was carried out using ASTM D698 – Standard Test for Laboratory Compaction Characteristics of Soil using Standard Effort. In Standard Proctor Test, a 2.5kg rammer falling through a height of 300mm is used to compact the soil in three layers into a standard compaction mould.

Standard compaction test were carry out by compacted 2500grams of soil mixed with PFA contents of 0, 9, 12, 15, 18, 21 and 24% with varying water content by using standard mould with measurement of: -

- Mould mass with base plate = 6320g
- Mould volume = 995.27cm$^3$
- Mould diameter = 104.7mm
- Mould Height = 115.6mm

Before compaction test were performed, the initial moisture content was used for calculating the correct moisture content of each compaction specimens. The amount of PFA was measured as percent of dry soil was added to the soil blend and mixed with mixer for about 10minutes and then the appropriate amount of water was added to produce homogeneous blend. The mixtures were immediately compacted into compaction mould for 3 layers with 25 blows in each layer and then were weighted with mould and its base. Next, a sample of mixtures was taken to find its water content. Then the specimens were removed from the mould, remixed with increment of ±3% of water and the test procedure repeated until a peak value is reached followed by two slightly lesser compacted masses. Finally, the moisture content versus dry density graph was plotted to determine the optimum moisture content of each percentage of PFA used.

### 3.2.2 Unconfined compression test

The unconfined compression test is used to measure the shearing resistance of cohesive soils which may be undisturbed or remolded specimens. An axial load is applied using either strain-control or stress-control condition. According to the ASTM D2166 – Standard Test Method for Unconfined Compressive Strength of Cohesive Soil, the unconfined compressive strength ($q_u$) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test.

Appropriate amount of soil was mixed together with different percentages of PFA at ±3% optimum water content from compaction test earlier. Then the soil-PFA mixtures were compacted into standard compaction mould and were extruded using universal extruder to get cylindrical samples. At the time preparing samples for unconfined compression test, the initial moisture content were also measured using the trimming of compacted sample. Samples were then being cut with the length ratio of 2 times its diameter, afterward were stored in plastic bags to maintain their moisture content and cured for 3 and 7 days in curing oven at temperature of $38^0$C. The stress-strain relationships were recorded along with their moisture content and lastly the shear strength, $c_u$ versus PFA percentages graph were plotted to determine the maximum shear strength for each percentages of PFA.

### 3.2.3 X-ray Fluorescence Spectrometry and X-ray Diffraction analysis

X-ray fluorescence (XRF) spectrometry is a non-destructive analytical technique used to identify and determine the concentrations of elements present in solid, powdered and liquid samples. XRF is capable of measuring elements from Beryllium (Be) to Uranium (U) and beyond at trace levels and up to 100%. The XRF spectrometer measures the individual component wavelengths of the fluorescent emission produced by a sample when irradiated with X-rays.

X-ray diffraction (XRD) has been in use in two main areas, for the fingerprint characterization of crystalline materials and the determination of their structure. Each crystalline solid has its unique characteristic X-ray powder pattern which may be used as a "fingerprint" for its identification. Once the material has been identified, X-ray crystallography may be used to determine its structure, i.e. how the atoms pack together in the crystalline state and what the interatomic distance and angle are etc. X-ray diffraction is one of the most important characterization tools used in solid state chemistry and materials science.

For this testing, XRF and XRD were used to determine the chemical composition of PFA and soil sample used. Only qualified person were conducted these experiment since it involved x-ray.

### 3.2.4 Scanning electron micrograph analysis (SEM)

An instrument similar to an electron microscope in that a beam of electrons instead of visible light is used to magnify the surface of a sample. The electrons are deflected, collected, accelerated, and directed against a scintillator. The surface image produced is of less magnification than that produced by an electron microscope, but it appears three dimensional and lifelike. The electrons emitted from the sample are then scanned to form a magnified image which allows the examination of the structure, relief, and morphology of materials at between 20 and 50000 times magnification. In addition to its great magnification, the SEM also has a great depth of field. Most SEM also have a facility to analyze the X-rays given off by the target as a result of its bombardment and, as each element in the periodic table produces its own X-ray spectrum, this can be used to determine the elemental content of the sample.

### 3.2.5 Energy dispersive x-ray analysis (EDX)

Energy dispersive x-ray spectroscopy (EDX) is a chemical microanalysis technique performed in conjunction with a SEM. The technique utilizes x-rays that are emitted from the sample during bombardment by the electron beam to characterize the elemental composition of the analyzed volume. Features or phases as small as about 1 μm can be analyzed.

When the sample is bombarded by the electron beam of the SEM, electrons are ejected from the atoms comprising the sample's surface. A resulting electron vacancy is filled by an electron from a higher shell, and an x-ray is emitted to balance the energy difference between the two electrons. The EDX measures the number of emitted x-rays versus their energy. The energy of the x-ray is characteristic of the element from which the x-ray was emitted. A spectrum of the energy versus relative counts of the detected x-rays is obtained and evaluated for qualitative and quantitative determinations of the elements present in the sampled volume.

### 3.3 Other material/equipment/apparatus

All the necessary equipment used for this study will be provided by Geotechnical Laboratory in UTP itself.

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 Basic engineering physical properties of PFA and soft soil

The soil sample used in this experiment had a natural moisture content of 29.44% and the index properties are summarized in Table 4.1(Refer Appendix for detail). From the plasticity index, the soil is categorized as medium plasticity. From the particles size distribution curve, the curve is steep, indicating most of the soil particles are the same which is predominantly by sand, thus the soil is classified as poorly graded sand with silt. The specific gravity of the soil is lower than the PFA, show that the PFA is heavier compared with the soil.

**Table 4.1: Engineering properties of soil and PFA**

| No. | Properties | Soft Soil | PFA |
|---|---|---|---|
| 1. | Specific Gravity | 2.53 | 2.63 |
| 2 | *Particle Size Distribution (%)* | | |
| | Gravel (> 4.75mm) | 0 | 0 |
| | Sand (4.75-0.075mm) | 94.31 | 83.37 |
| | Silt (0.075mm-0.002mm) | 3.31 | 16.63 |
| | Clay (<0.002mm) | 2.26 | - |
| 3 | *Atterberg Limit (%)* | | |
| | Plastic Limit | 32.17 | - |
| | Liquid Limit | 49.20 | |
| | Plasticity Index | 17.03 | |
| 4 | *Soil classification* | | |
| | USCS | SP-SW | - |
| | ASSHTO | A-3 | |

## 4.2 Test on soil samples mixed with PFA

### 4.2.1 Effect of PFA in soil on compaction behavior

Table 4.2 shows a variation of optimum moisture content (OMC) and maximum dry density weight with an increase in percent of PFA based on standard compaction test. The moisture content and dry density increased and decreased randomly for all samples. Optimum moisture content had decreased when PFA was added into the soil, maybe due to hydration reaction of PFA to form cementation material. Decrease in maximum dry density had made the specific gravity increased. This may be due to PFA was added to soil, it changed the porosity and void ratio of the mixture since the PFA specific gravity is higher than the soil itself. The maximum dry density of the soil-PFA mixture was 1.79 g/cm$^3$ with optimum moisture content of 15% for 12% of PFA.

**Table 4.2: Effect of PFA in soil on OMC, maximum dry density and specific gravity**

| PFA (%) | 0 | 9 | 12 | 15 | 18 | 21 | 24 | 100 |
|---|---|---|---|---|---|---|---|---|
| Maximum Dry Density (g/cm$^3$) | 1.73 | 1.76 | 1.79 | 1.73 | 1.71 | 1.74 | 1.72 | - |
| OMC (%) | 17.5 | 12.1 | 15.0 | 14.8 | 15.8 | 15.8 | 15.4 | - |
| Specific Gravity | 2.53 | 2.46 | 2.41 | 2.52 | 2.44 | 2.46 | 2.00 | 2.63 |

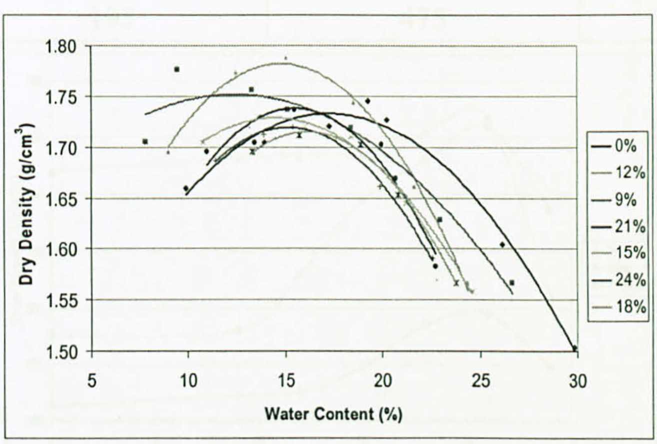


**Figure 4.1: Standard Compaction Result of soil with varying percentages of PFA**

### 4.2.2 Effect of PFA in soil on shear strength

Table 4.3 shows the measured values of shear strength ($c_u$) with varying percentages of PFA. The shear strength increased non-linearly with an increase of PFA but then it decreased after addition of 24% of PFA. Results showed that the samples gained higher strength when added with 21% of PFA and the greatest shear strength occurred in 7 days cure due to rapid hydration reaction of Class C PFA while all samples with 24% of PFA demonstrate decreasing in shear strength value. This may be caused by the decrease in the pozzolanic reaction when too much PFA was added. During observation, all samples failed with a visible shear failure with an angle of $60^{o}$-$65^{o}$ for immediately test and after 3 and 7 days, the samples became very brittle due to loss of moisture content.

**Table 4.3: Effect of PFA on shear strength of soil with curing condition**

| PFA (%) | Immediately test (kPa) | 3 days curing (kPa) | 7 days curing (kPa) |
|---|---|---|---|
| 0 | 125 | 250 | 540 |
| 9 | 145 | 260 | 565 |
| 12 | 150 | 360 | 567.5 |
| 15 | 195 | 490 | 570 |
| 18 | 270 | 560 | 610 |
| **21** | **289.5** | **620** | **636** |
| 24 | 195 | 475 | 320 |

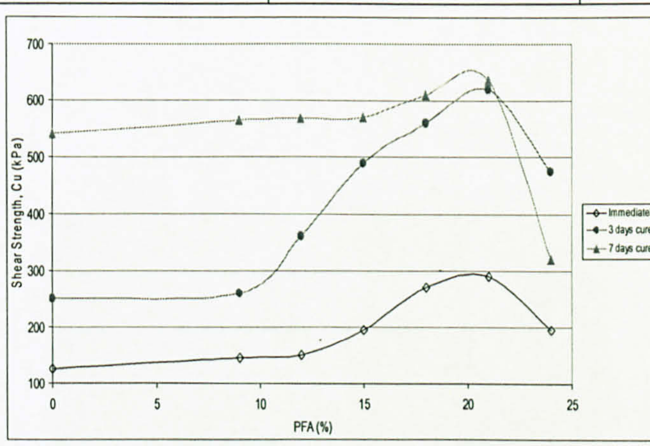


**Figure 4.2: Shear strength, Cu of soil with varying percentages of PFA**

### 4.2.3 Effect of PFA in soil on Atterberg Limit

Fig 4.3 summarizes the effect of PFA on Atterberg Limit of the soil. The LL and PL decreased when higher PFA content was added. In general, as the LL and PL decrease, the soil usually becomes better in term of taking loads. The increased in PL for 24% PFA indicated that the sample becomes finer grain and more plastic. This is undesirable for soil stabilization since it will reduce the shear strength of the mixtures as mentioned in 4.2.2. Reduction of plasticity index was about 15% when the PFA content was 21%.

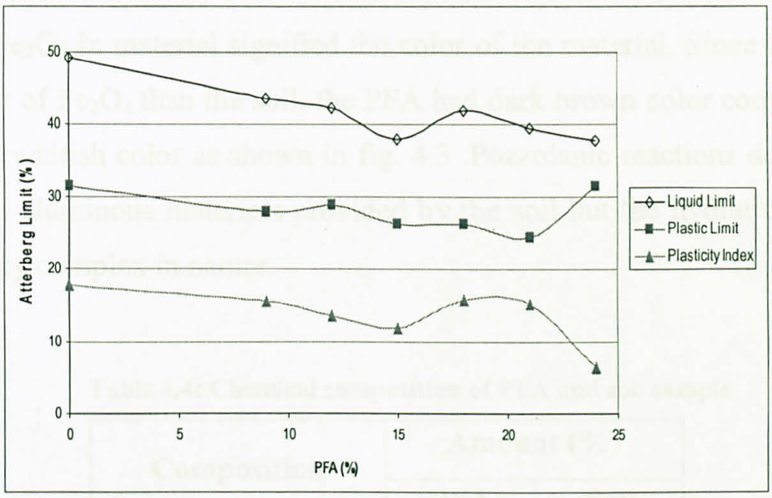


**Figure 4.3: Effect of PFA in soil on Atterberg Limit**

### 4.2.4 X-ray Fluorescence Spectrometry and X-ray Diffraction analysis

The PFA and soil samples were tested in order to know their chemical composition and the results were shown in Table 4.4. From the result, the combined amount of silicon dioxide ($SiO_2$), aluminum oxide ($Al_2O_3$) and iron oxide ($Fe_2O_3$) for PFA is 66.7% with sulfur trioxide ($SO_3$), 1.38%. Thus the PFA is classified is a Class C PFA with small amount of lime (CaO), 7.59% (ASTM C618). The result also stated that the soil had significant amount of $SiO_2$ of 63.4% and from XRD analysis it specified that it was predominant by quartz mineral. Meanwhile for the PFA, it was predominant by sodium calcium silicate mineral (Refer to Appendix). Amount of $Fe_2O_3$ in material signified the color of the material. Since the PFA had more amount of $Fe_2O_3$ than the soil, the PFA had dark brown color compared to the soil that had whitish color as shown in fig. 4.3 .Pozzolanic reactions depend on the siliceous and aluminous materials provided by the soil but the hydration chemistry of PFA is very complex in nature.

**Table 4.4: Chemical composition of PFA and soil sample**

| Composition | Amount (%) | |
|---|---|---|
| | PFA | Soil |
| $SiO_2$ | 26.5 | 63.4 |
| $Al_2O_3$ | 10.5 | 31.1 |
| $Fe_2O_3$ | 29.7 | 1.46 |
| $SO_3$ | 1.38 | 0.05 |
| CaO | 7.49 | 0.01 |

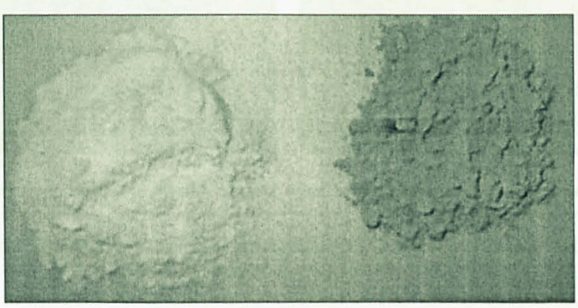

**Figure 4.4: From left: Soil and PFA**

### 4.2.5 Scanning electron micrograph analysis (SEM)

Fig 4.4 below shows the microscopic for PFA and untreated soil. As mentioned in Chapter 2, PFA consists of fine, powdery particles that are predominantly spherical in shape, either solid or hollow, and mostly glassy (amorphous) in nature as illustrated in fig. 4.4(a), while for untreated soil, as in fig. 4.4(b) the soil having irregular shape and scatter similar to cotton. For treated soil, it contained larger particle, very dense and lesser voids compare with untreated soil and from fig 4.5(a) and (b) it showed that the particles were bonding together with PFA. From immediate test to 7 days curing, the mineral particles changed from irregular shape and sizes into more similar shape and sizes and had parallel layer to each other.

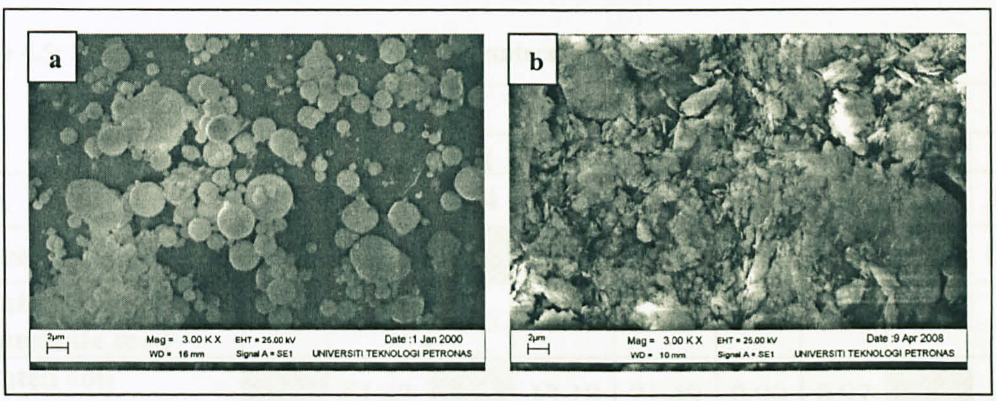

**Figure 4.5: SEM for a) PFA b) untreated soil**

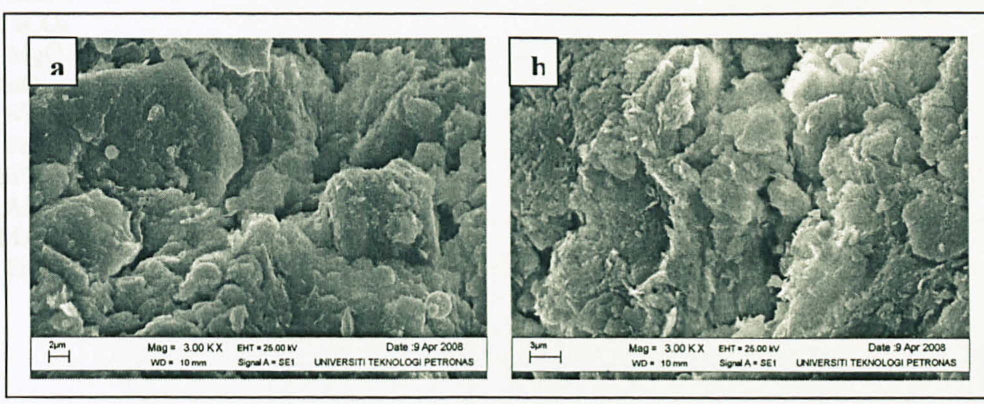

**Figure 4.6: SEM for a) treated soil for immediately test b) treated soil for 7 days curing**

### 4.2.6 Energy dispersive x-ray analysis (EDX)

The EDX analysis was done after SEM analysis and the summary of the results were tabulated in table 4.5. The untreated soil had no presence of C, Mg and Ca element but after being treated with PFA the composition of the soil was changed. The analysis had detected presence of those three elements in treated soil for immediate test but not after the 7 days curing. Comparing the element percentages in untreated and treated soil, the amount had slightly increased in almost every elements. This maybe due to the formation of cementations materials when PFA was added into the soil binding the materials together to form calcium silicate gel or calcium aluminate gel. This is also justified from the SEM analysis where the soil particles became larger and bonding together after being treated with PFA.

**Table 4.5: Summary of EDX analysis for PFA, untreated and treated soil**

| | Element (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **C** | **O** | **Mg** | **Al** | **Si** | **K** | **Ca** | **Ti** | **Fe** |
| **PFA** | 3.09 | 54.92 | 1.44 | 11.22 | 21.11 | 1.75 | 2.14 | 0.56 | 3.77 |
| **Untreated Soil** | | 61.22 | | 14.18 | 21.38 | 1.20 | | 1.17 | 0.85 |
| **Treated soil (immediate test)** | 2.45 | 63.46 | 0.46 | 13.10 | 21.81 | 1.02 | 0.62 | 0.48 | 1.49 |
| **Treated soil (7 days curing)** | | 61.42 | | 13.19 | 21.49 | 0.90 | 0.97 | | 2.03 |

Standard:
C $CaCO_3$
Mg MgO
Si $SiO_2$
Ca Wollastonite
Fe Fe
O $SiO_2$
Al $Al_2O_3$
K MAD-10 Feldspar
Ti Ti

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

The experiments conducted to study the effect of PFA in soils resulted in the following conclusions:-

1. The PFA was classified as Class C PFA while the soil was predominantly quartz and had medium plasticity. The result showed that when PFA was added into soil it had some cementations material.

2. Addition of PFA in soil decreases the dry density and moisture content. The optimum dry density achieved when 12% PFA was added into the soils with water content of 15%.

3. By adding 21% of PFA, the shear strength was increased up to 50% for immediate test, 7% and 15% for 3 and 7 days curing time, respectively. However the strength decreases when 24 % of PFA was added maybe due to the decreasing pozzolanic reaction. Every sample failed with a visible shear failure with an angle of $60^{o}$-$65^{o}$ and after curing the samples became very brittle due to loss of moisture content.

4. The Atterberg limit of soil mixed with PFA decreases with the increasing amount of PFA. It also reduced the plasticity characteristics of the mixture about 15% by adding 21% PFA.

5. The behavior of the soil mixed with PFA was changed due to chemical reaction between these two materials. The particles of soil-PFA mixtures became more solid, dense and contain lesser air voids especially during 7 days of curing. The particles sizes of soil-PFA mixtures also became larger compared before the soil being treated with PFA.

From the experiments conducted, it can be concluded that the addition of Class C PFA has improved the engineering properties of the soil significantly. Hence, PFA can be utilized for soil improvement in shear strength hence improves the soil characteristics. Frequent usage of PFA in soil stabilization may reduce the disposal problem for PFA in future.

## 5.2 Recommendation

Throughout this project, there are several aspects recommended for future study in order to improve the soil engineering properties and to utilize the usage of PFA. Some of the recommendations are: -

- To use different type of soils to observe the soil improvement
- To propose the idea of using PFA for soil stabilization to soil treatment company
- To determine the cost analysis using PFA stabilization and comparing with the commonly used stabilizer like lime or cement

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25. ASTM D 422 - Standard Test Method for Particle-Size Analysis of Soils

26. ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit and Plasticity Index of Soils

27. ASTM D 698 - Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort

28. ASTM D 2166 – Standard Test Method for Unconfined Compressive Strength of Cohesive Soil

29. BS 1377 - Standard Test Method for Liquid Limit of Soils by Using Fall Cone Method

# APPENDICES

**Table A. 1: Particle Size Distribution for soil sample**

| Sieve No | Opening (mm) | Mass of Empty Sieve (g) | Mass Sieve + Soil Retained (g) | Mass Retained (g) | % Retained | Cummulative % Retained | % Passing |
|---|---|---|---|---|---|---|---|
| 10.00 | 2.00 | 456.20 | 456.80 | 0.60 | 0.12 | 0.12 | 99.88 |
| 16 | 1.180 | 424.60 | 442.20 | 17.60 | 3.54 | 3.66 | 96.34 |
| 30 | 0.600 | 405.90 | 443.70 | 37.80 | 7.60 | 11.26 | 88.74 |
| 40 | 0.425 | 367.70 | 395.20 | 27.50 | 5.53 | 16.79 | 83.21 |
| 50 | 0.300 | 370.70 | 410.80 | 40.10 | 8.06 | 24.85 | 75.15 |
| 100 | 0.150 | 336.00 | 474.90 | 138.90 | 27.93 | 52.77 | 47.23 |
| 200 | 0.075 | 254.10 | 452.80 | 198.70 | 39.95 | 92.72 | 7.28 |
| - | 0.063 | 328.10 | 336.60 | 8.50 | 1.71 | 94.43 | 5.57 |
| Pan | 0.00 | 389.50 | 417.20 | 27.70 | 5.57 | 100.00 | 0.00 |
| **Total** | | | | 497.40 | 100.00 | | |

**Table A. 2: Particle Size Distribution for PFA sample**

| Sieve No | Opening (mm) | Mass of Empty Sieve (g) | Mass Sieve + Soil Retained (g) | Mass Retained (g) | % Retained | Cummulative % Retained | % Passing |
|---|---|---|---|---|---|---|---|
| 10.00 | 2.00 | 470.08 | 479.46 | 9.38 | 0.63 | 0.63 | 99.37 |
| 16 | 1.180 | 427.76 | 430.20 | 2.44 | 0.16 | 0.79 | 99.21 |
| 30 | 0.600 | 389.65 | 413.48 | 23.83 | 1.60 | 2.39 | 97.61 |
| 40 | 0.425 | 369.56 | 375.13 | 5.57 | 0.37 | 2.77 | 97.23 |
| 50 | 0.300 | 370.71 | 386.42 | 15.71 | 1.05 | 3.82 | 96.18 |
| - | 0.212 | 346.85 | 372.74 | 25.89 | 1.74 | 5.56 | 94.44 |
| 100 | 0.150 | 337.97 | 379.37 | 41.40 | 2.78 | 8.34 | 91.66 |
| 200 | 0.075 | 255.47 | 1318.61 | 1063.14 | 71.36 | 79.70 | 20.30 |
| - | 0.063 | 328.01 | 388.95 | 60.94 | 4.09 | 83.79 | 16.21 |
| Pan | - | 396.29 | 637.78 | 241.49 | 16.21 | 100.00 | 0.00 |
| **Total** | | | | **1489.79** | **100.00** | | |

Table A. 3: Hydrometer test for soil sample

| Time | Actual Hydrometer Reading | Hydrometer Correction for Meniscus | Effective Length | K factor | D (mm) | $C_T$ | a | Hydrometer Correction $R_C$ | % finer P | & adjusted finer $P_A$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 | 1.0300 | 1.0350 | 7.00 | 0.01257 | 0.04703 | 1.21 | 1.028 | 1.2400 | 2.5494 | 2.2919 |
| 1 | 1.0290 | 1.0340 | 7.30 | 0.01257 | 0.03396 | 1.21 | 1.028 | 1.2390 | 2.5474 | 2.2901 |
| 2 | 1.0265 | 1.0315 | 7.65 | 0.01257 | 0.02458 | 1.21 | 1.028 | 1.2365 | 2.5422 | 2.2855 |
| 4 | 1.0245 | 1.0295 | 8.35 | 0.01257 | 0.01816 | 1.21 | 1.028 | 1.2345 | 2.5381 | 2.2818 |
| 8 | 1.0225 | 1.0275 | 9.05 | 0.01257 | 0.01337 | 1.21 | 1.028 | 1.2325 | 2.5340 | 2.2781 |
| 30 | 1.0195 | 1.0245 | 9.85 | 0.01257 | 0.00720 | 1.21 | 1.028 | 1.2295 | 2.5279 | 2.2725 |
| 120 | 1.0170 | 1.0220 | 10.50 | 0.01257 | 0.00372 | 1.21 | 1.028 | 1.2270 | 2.5227 | 2.2679 |
| 480 | 1.0150 | 1.0200 | 11.00 | 0.01257 | 0.00190 | 1.21 | 1.028 | 1.2250 | 2.5186 | 2.2642 |
| 1440 | 1.0135 | 1.0185 | 11.40 | 0.01257 | 0.00112 | 1.21 | 1.028 | 1.2235 | 2.5155 | 2.2614 |

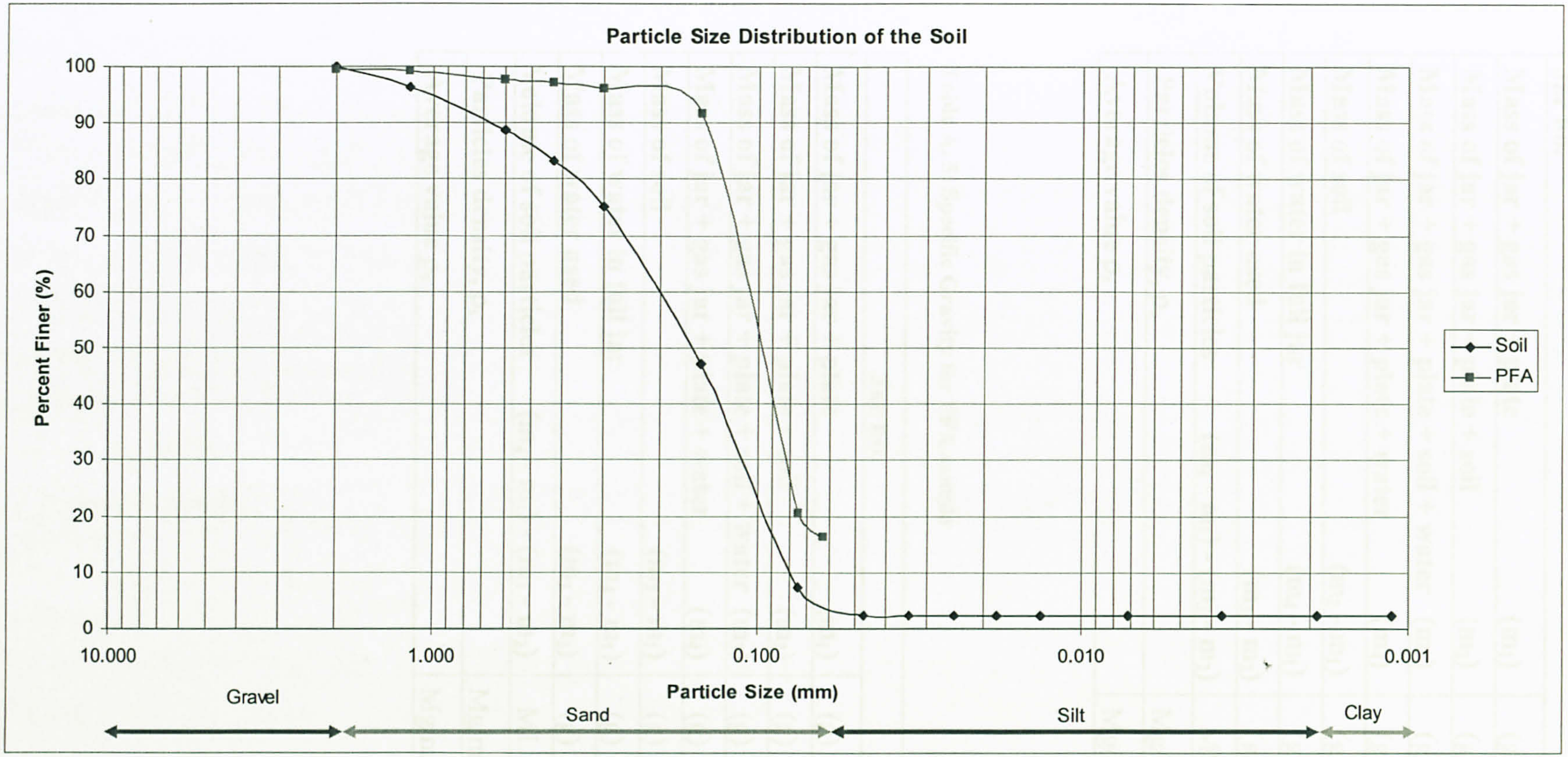



**Figure A. 1: Particles size distribution for soil and PFA**

**Table A. 4: Specific Gravity for soil sample**

| Jar no. | | | 1 | 2 | 3 |
|---|---|---|---|---|---|
| Mass of jar + gas jar + plate | $(m_1)$ | (g) | 532.80 | 537.60 | 535.90 |
| Mass of jar + gas jar + plate + soil | $(m_2)$ | (g) | 932.90 | 938.90 | 936.00 |
| Mass of jar + gas jar + plate + soil + water | $(m_3)$ | (g) | 1795.71 | 1805.67 | 1788.10 |
| Mass of jar + gas jar + plate + water | $(m_4)$ | (g) | 1557.28 | 1547.06 | 1562.00 |
| Mass of soil | $(m_2 - m_1)$ | (g) | 400.10 | 401.30 | 400.10 |
| Mass of water in full jar | $(m_4 - m_1)$ | (g) | 1024.48 | 1009.46 | 1026.10 |
| Mass of water used | $(m_3 - m_2)$ | (g) | 862.81 | 866.77 | 852.10 |
| Volume of soil particles | $(m_4 - m_1) - (m_3 - m_2)$ | ML | 161.67 | 142.69 | 174.00 |
| Particles density, $\rho_s$ | | $Mg/m^3$ | 2.47 | 2.81 | 2.30 |
| Average value $\rho_s$ | | $Mg/m^3$ | | **2.53** | |

**Table A. 5: Specific Gravity for PFA sample**

| Jar no. | | | 1 | 2 | 3 |
|---|---|---|---|---|---|
| Mass of jar + gas jar + plate | $(m_1)$ | (g) | 535.80 | 537.62 | 541.10 |
| Mass of jar + gas jar + plate + soil | $(m_2)$ | (g) | 934.04 | 939.23 | 937.57 |
| Mass of jar + gas jar + plate + soil + water | $(m_3)$ | (g) | 1808.65 | 1823.24 | 1813.92 |
| Mass of jar + gas jar + plate + water | $(m_4)$ | (g) | 1566.08 | 1573.67 | 1564.35 |
| Mass of soil | $(m_2 - m_1)$ | (g) | 398.24 | 401.61 | 396.47 |
| Mass of water in full jar | $(m_4 - m_1)$ | (g) | 1030.28 | 1036.05 | 1023.25 |
| Mass of water used | $(m_3 - m_2)$ | (g) | 874.61 | 884.01 | 876.35 |
| Volume of soil particles | $(m_4 - m_1) - (m_3 - m_2)$ | ML | 155.67 | 152.04 | 146.90 |
| Particles density, $\rho_s$ | | $Mg/m^3$ | 2.56 | 2.64 | 2.70 |
| Average value $\rho_s$ | | $Mg/m^3$ | | **2.63** | |

Table A. 6: Specific Gravity for soil mixed with PFA

| PFA (%) | | | 9 | 12 | 15 | 18 | 21 | 24 |
|---|---|---|---|---|---|---|---|---|
| Mass of jar + gas jar + plate | ($m_1$) | (g) | 534.10 | 535.90 | 535.80 | 537.80 | 535.30 | 533.10 |
| Mass of jar + gas jar + plate + soil | ($m_2$) | (g) | 970.10 | 983.90 | 995.80 | 1009.80 | 1019.30 | 1029.10 |
| Mass of jar + gas jar + plate + soil + water | ($m_3$) | (g) | 1816.30 | 1834.50 | 1819.90 | 1841.20 | 1858.50 | 1847.00 |
| Mass of jar + gas jar + plate + water | ($m_4$) | (g) | 1557.30 | 1572.20 | 1542.80 | 1562.80 | 1571.10 | 1599.00 |
| Mass of soil | ($m_2$ - $m_1$) | (g) | 436.00 | 448.00 | 460.00 | 472.00 | 484.00 | 496.00 |
| Mass of water in full jar | ($m_4$ - $m_1$) | (g) | 1023.20 | 1036.30 | 1007.00 | 1025.00 | 1035.80 | 1065.90 |
| Mass of water used | ($m_3$ - $m_2$) | (g) | 846.20 | 850.60 | 824.10 | 831.40 | 839.20 | 817.90 |
| Volume of soil particles | ($m_4$ - $m_1$) - ($m_3$ - $m_2$) | ML | 177.00 | 185.70 | 182.90 | 193.60 | 196.60 | 248.00 |
| Average particles density, $\rho_s$ | | Mg/m$^3$ | **2.46** | **2.41** | **2.52** | **2.44** | **2.46** | **2.00** |

Table A. 7; Liquid limit for soil sample 1

| Test No | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| Initial dial gauge reading (mm) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Final dial gauge reading (mm) | 15.00 | 15.30 | 17.90 | 17.90 | 18.40 | 17.90 |
| Average Penetration (mm) | 15.15 | | 17.90 | | 18.15 | |
| Container No. | 1 | | 2 | | 3 | |
| Mass of wet soil + container (g) | 37.90 | | 32.13 | | 35.57 | |
| Mass of dry soil + container (g) | 32.23 | | 28.20 | | 31.70 | |
| Mass of container (g) | 19.87 | | 19.87 | | 23.67 | |
| Mass of moisture (g) | 5.67 | | 3.93 | | 3.87 | |
| Mass of dry soil (g) | 12.36 | | 8.33 | | 8.03 | |
| Moisture content % | 45.87 | | 47.18 | | 48.19 | |

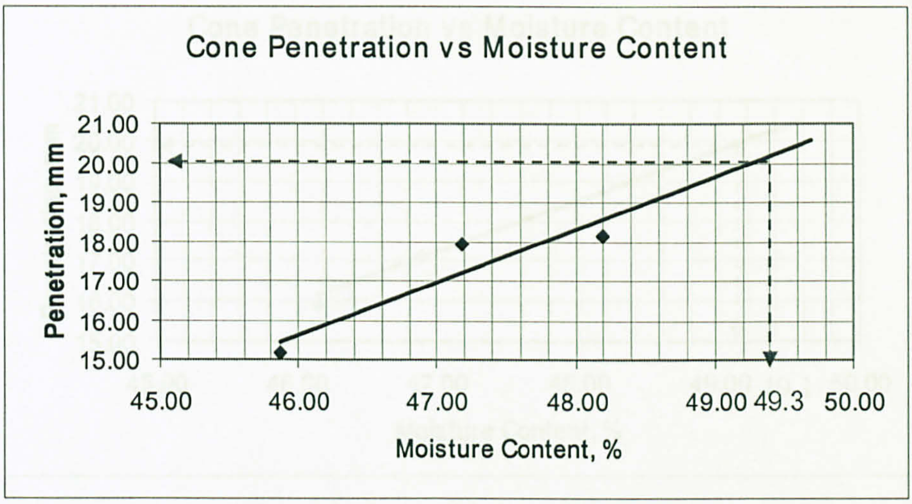



Figure A. 2: Liquid limit for soil sample 1

**Table A. 8: Liquid limit for soil sample 2**

| Test No | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| **Initial dial gauge reading (mm)** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Final dial gauge reading (mm)** | 15.90 | 15.90 | 16.70 | 16.40 | 17.00 | 17.20 |
| **Average Penetration (mm)** | 15.90 | | 16.55 | | 17.10 | |
| **Container No.** | 1 | | 2 | | 3 | |
| **Mass of wet soil + container (g)** | 61.90 | | 56.30 | | 54.80 | |
| **Mass of dry soil + container (g)** | 52.53 | | 46.07 | | 44.67 | |
| **Mass of container (g)** | 32.23 | | 23.93 | | 23.07 | |
| **Mass of moisture (g)** | 9.37 | | 10.23 | | 10.13 | |
| **Mass of dry soil (g)** | 20.30 | | 22.14 | | 21.60 | |
| **Moisture content %** | 46.16 | | 46.21 | | 46.90 | |

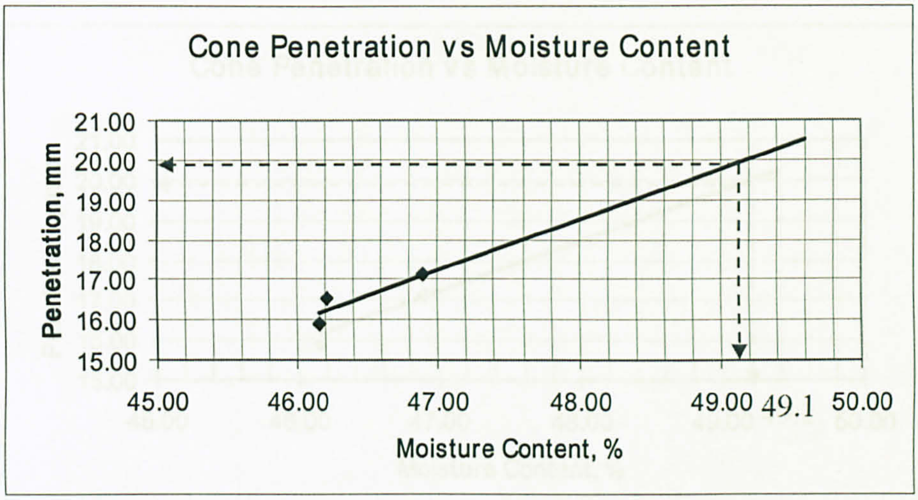



**Figure A. 3: Liquid limit for soil sample 2**

**Table A. 9: Liquid limit for soil sample 3**

| Test No | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| **Initial dial gauge reading (mm)** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Final dial gauge reading (mm)** | 17.00 | 17.40 | 17.80 | 18.10 | 19.00 | 19.10 |
| **Average Penetration (mm)** | 17.20 | | 17.95 | | 19.05 | |
| **Container No.** | **1** | | **2** | | **3** | |
| **Mass of wet soil + container (g)** | 39.80 | | 43.30 | | 47.83 | |
| **Mass of dry soil + container (g)** | 34.10 | | 37.03 | | 40.97 | |
| **Mass of container (g)** | 20.87 | | 23.18 | | 26.50 | |
| **Mass of moisture (g)** | 5.70 | | 6.27 | | 6.86 | |
| **Mass of dry soil (g)** | 13.23 | | 13.85 | | 14.47 | |
| **Moisture content %** | 43.08 | | 45.27 | | 47.41 | |

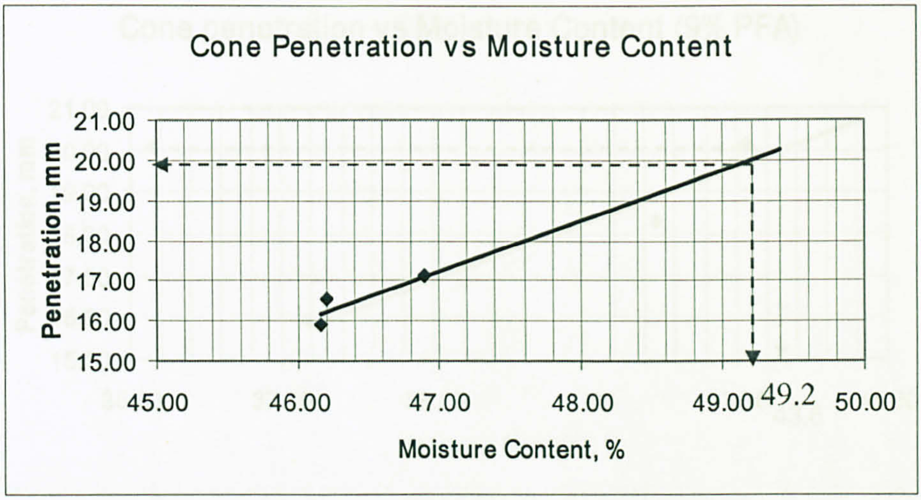



**Figure A. 4: Liquid limit for soil sample 3**

**Table A. 10: Liquid limit for 9% PFA**

| Test No | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| **Initial dial gauge reading (mm)** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Final dial gauge reading (mm)** | 16.00 | 15.80 | 18.30 | 18.30 | 20.00 | 20.30 |
| **Average Penetration (mm)** | 15.90 | | 18.30 | | 20.15 | |
| **Container No.** | **1** | | **2** | | **3** | |
| **Mass of wet soil + container (g)** | 47.10 | | 56.65 | | 49.00 | |
| **Mass of dry soil + container (g)** | 39.70 | | 49.75 | | 40.20 | |
| **Mass of container (g)** | 19.90 | | 33.30 | | 19.80 | |
| **Mass of moisture (g)** | 7.40 | | 6.90 | | 8.80 | |
| **Mass of dry soil (g)** | 19.80 | | 16.45 | | 20.40 | |
| **Moisture content %** | 37.37 | | 41.95 | | 43.14 | |

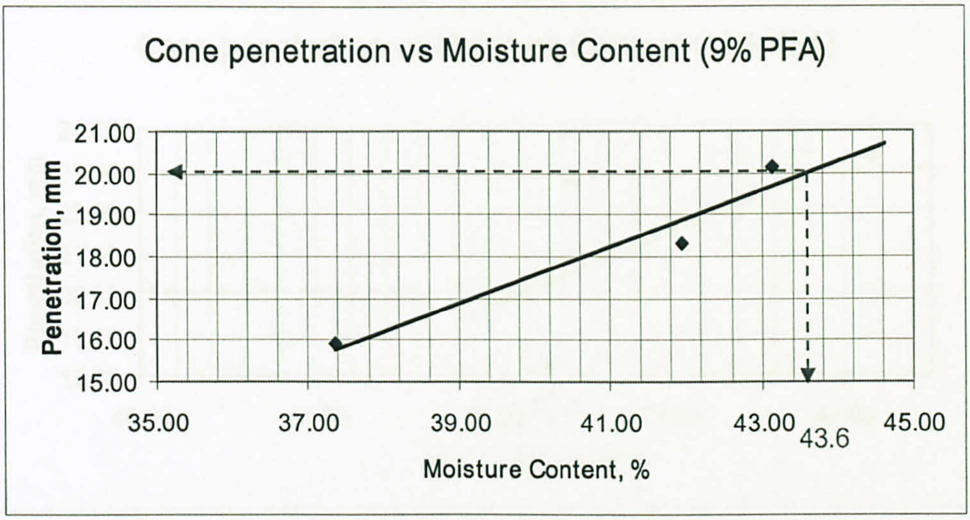



**Figure A. 5: Liquid limit for 9% PFA**

**Table A. 11: Liquid limit for 12% PFA**

| Test No | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| Initial dial gauge reading (mm) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Final dial gauge reading (mm) | 18.20 | 18.30 | 22.90 | 22.50 | 23.30 | 23.20 |
| Average Penetration (mm) | 18.25 | | 22.70 | | 23.25 | |
| Container No. | 1 | | 2 | | 3 | |
| Mass of wet soil + container (g) | 46.45 | | 46.80 | | 47.75 | |
| Mass of dry soil + container (g) | 38.45 | | 38.90 | | 39.05 | |
| Mass of container (g) | 19.55 | | 20.30 | | 19.35 | |
| Mass of moisture (g) | 8.00 | | 7.90 | | 8.70 | |
| Mass of dry soil (g) | 18.90 | | 18.60 | | 19.70 | |
| Moisture content % | 42.33 | | 42.47 | | 44.16 | |

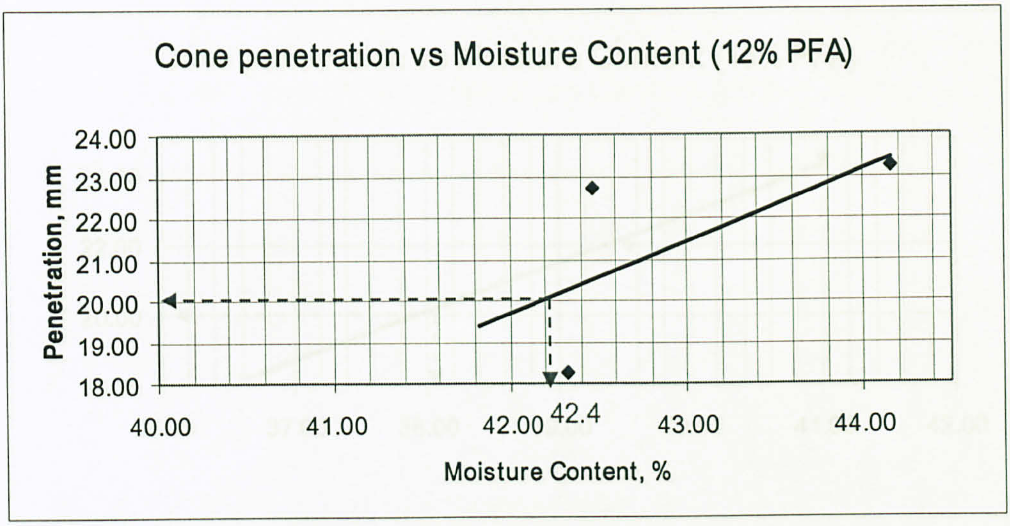



**Figure A. 6: Liquid limit for 12% PFA**

**Table A. 12: Liquid limit for 15% PFA**

| Test No | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| Initial dial gauge reading (mm) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Final dial gauge reading (mm) | 18.30 | 18.20 | 22.10 | 21.90 | 24.50 | 24.40 |
| Average Penetration (mm) | 18.25 | | 22.00 | | 24.45 | |
| Container No. | 1 | | 2 | | 3 | |
| Mass of wet soil + container (g) | 45.10 | | 55.45 | | 58.15 | |
| Mass of dry soil + container (g) | 38.05 | | 46.85 | | 49.70 | |
| Mass of container (g) | 18.80 | | 25.10 | | 29.10 | |
| Mass of moisture (g) | 7.05 | | 8.60 | | 8.45 | |
| Mass of dry soil (g) | 19.25 | | 21.75 | | 20.60 | |
| Moisture content % | 36.62 | | 39.54 | | 41.02 | |

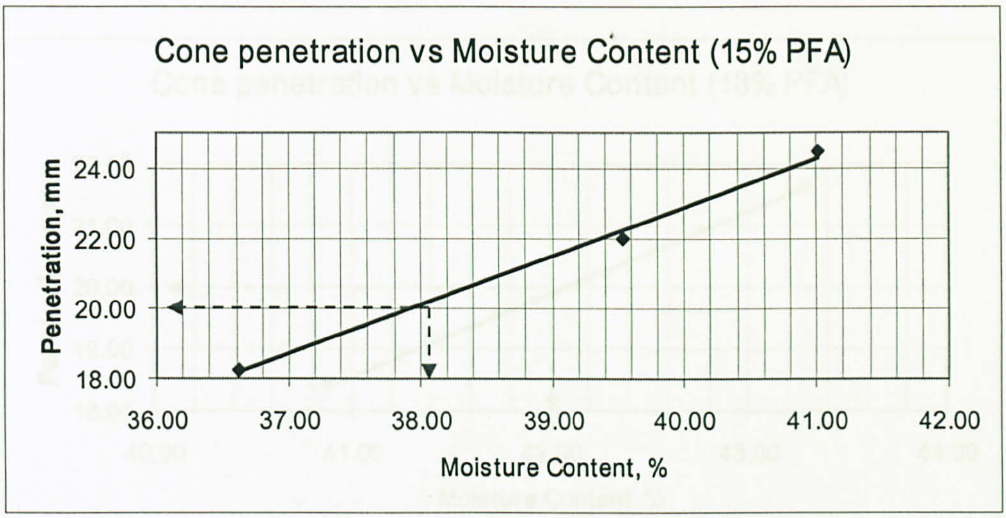



**Figure A. 7: Liquid limit for 15% PFA**

**Table A. 13: Liquid limit for 18% PFA**

| Test No | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| Initial dial gauge reading (mm) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Final dial gauge reading (mm) | 18.50 | 18.30 | 20.00 | 20.50 | 21.80 | 21.50 |
| Average Penetration (mm) | 18.40 | | 20.25 | | 21.65 | |
| Container No. | **1** | | **3** | | **2** | |
| Mass of wet soil + container (g) | 41.70 | | 50.40 | | 46.00 | |
| Mass of dry soil + container (g) | 35.20 | | 42.60 | | 38.10 | |
| Mass of container (g) | 19.30 | | 24.15 | | 19.85 | |
| Mass of moisture (g) | 6.50 | | 7.80 | | 7.90 | |
| Mass of dry soil (g) | 15.90 | | 18.45 | | 18.25 | |
| Moisture content % | 40.88 | | 42.28 | | 43.29 | |

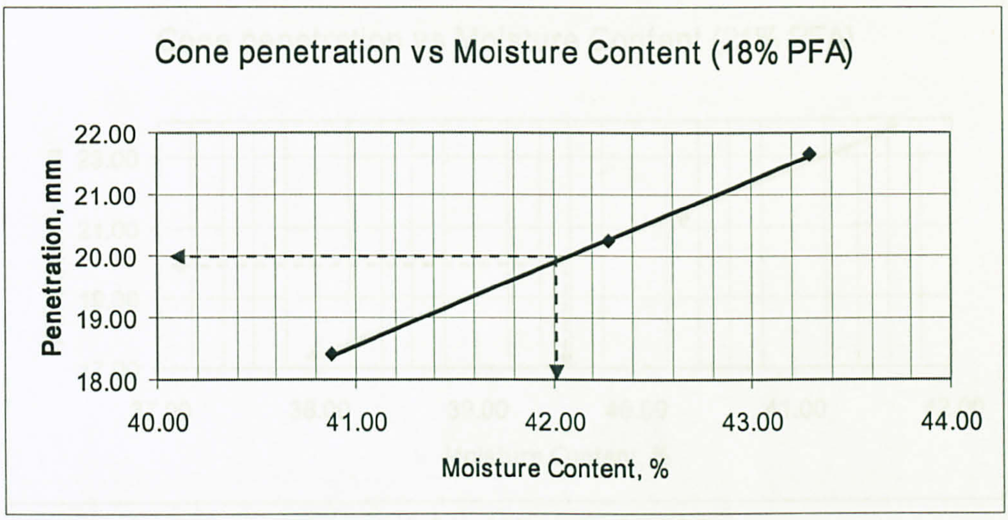



**Figure A. 8: Liquid limit for 18% PFA**

**Table A. 14: Liquid limit for 21% PFA**

| Test No | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| Initial dial gauge reading (mm) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Final dial gauge reading (mm) | 17.30 | 17.40 | 21.10 | 21.30 | 23.80 | 23.90 |
| Average Penetration (mm) | 17.35 | | 21.20 | | 23.85 | |
| Container No. | **1** | | **2** | | **3** | |
| Mass of wet soil + container (g) | 47.25 | | 46.75 | | 49.00 | |
| Mass of dry soil + container (g) | 39.75 | | 38.95 | | 40.55 | |
| Mass of container (g) | 20.00 | | 19.60 | | 20.25 | |
| Mass of moisture (g) | 7.50 | | 7.80 | | 8.45 | |
| Mass of dry soil (g) | 19.75 | | 19.35 | | 20.30 | |
| Moisture content % | 37.97 | | 40.31 | | 41.63 | |

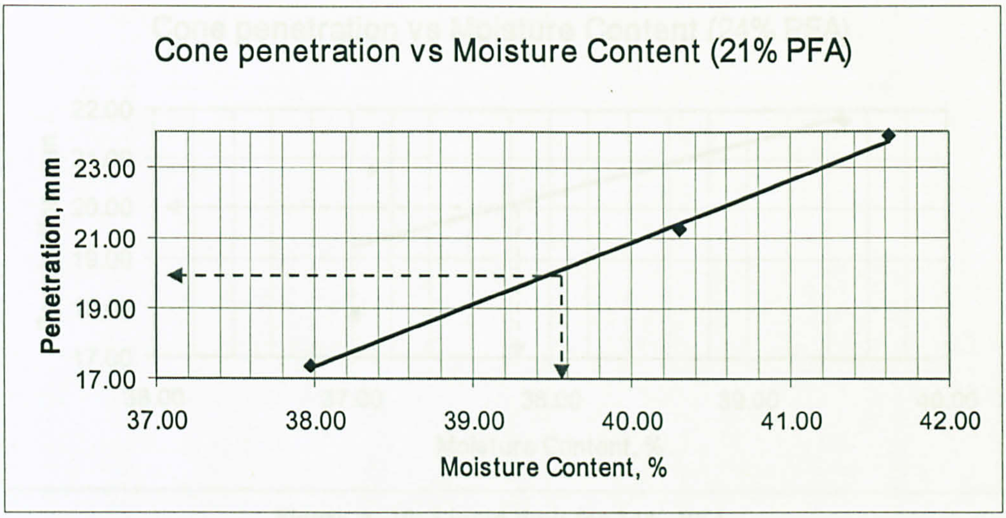



**Figure A. 9: Liquid limit for 21% PFA**

**Table A. 15: Liquid limit for 24% PFA**

| Test No | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| Initial dial gauge reading (mm) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Final dial gauge reading (mm) | 17.50 | 18.20 | 20.90 | 20.60 | 22.00 | 21.60 |
| Average Penetration (mm) | 17.85 | | 20.75 | | 21.80 | |
| Container No. | 1 | | 2 | | 3 | |
| Mass of wet soil + container (g) | 46.25 | | 49.90 | | 51.90 | |
| Mass of dry soil + container (g) | 39.05 | | 41.70 | | 44.30 | |
| Mass of container (g) | 19.60 | | 19.60 | | 25.05 | |
| Mass of moisture (g) | 7.20 | | 8.20 | | 7.60 | |
| Mass of dry soil (g) | 19.45 | | 22.10 | | 19.25 | |
| Moisture content % | 37.02 | | 37.10 | | 39.48 | |

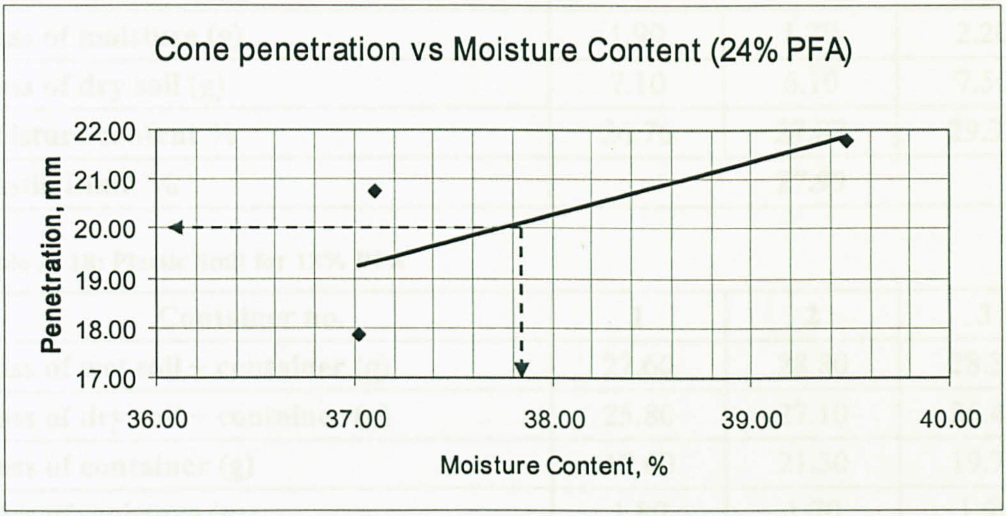



**Figure A. 10: Liquid limit for 24% PFA**

Table A. 16: Plastic limit for soil sample

| Container no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Mass of wet soil + container (g) | 27.80 | 27.00 | 28.30 | 27.50 | 27.10 | 27.50 | 26.20 |
| Mass of dry soil + container (g) | 26.20 | 25.20 | 25.80 | 25.70 | 25.00 | 25.30 | 24.40 |
| Mass of container (g) | 20.80 | 19.50 | 18.70 | 19.70 | 18.90 | 18.90 | 18.40 |
| Mass of moisture (g) | 1.60 | 1.80 | 2.50 | 1.80 | 2.10 | 2.20 | 1.80 |
| Mass of dry soil (g) | 5.40 | 5.70 | 7.10 | 6.00 | 6.10 | 6.40 | 6.00 |
| Moisture content % | 29.63 | 31.58 | 35.21 | 30.00 | 34.43 | 34.38 | 30.00 |
| Plastic Limit % | | | | 32.17 | | | |

Table A. 17: Plastic limit for 9% PFA

| Container no. | 1 | 2 | 3 |
|---|---|---|---|
| Mass of wet soil + container (g) | 28.60 | 26.30 | 29.50 |
| Mass of dry soil + container (g) | 26.70 | 24.60 | 27.30 |
| Mass of container (g) | 19.60 | 18.50 | 19.80 |
| Mass of moisture (g) | 1.90 | 1.70 | 2.20 |
| Mass of dry soil (g) | 7.10 | 6.10 | 7.50 |
| Moisture content % | 26.76 | 27.87 | 29.33 |
| Plastic Limit % | | 27.99 | |

Table A. 18: Plastic limit for 12% PFA

| Container no. | 1 | 2 | 3 |
|---|---|---|---|
| Mass of wet soil + container (g) | 27.60 | 28.80 | 28.30 |
| Mass of dry soil + container (g) | 25.80 | 27.10 | 26.40 |
| Mass of container (g) | 19.60 | 21.30 | 19.70 |
| Mass of moisture (g) | 1.80 | 1.70 | 1.90 |
| Mass of dry soil (g) | 6.20 | 5.80 | 6.70 |
| Moisture content % | 29.03 | 29.31 | 28.36 |
| Plastic Limit % | | 28.90 | |

Table A. 19: Plastic limit for 15% PFA

| Container no. | 1 | 2 | 3 |
|---|---|---|---|
| Mass of wet soil + container (g) | 28.10 | 30.00 | 30.60 |
| Mass of dry soil + container (g) | 26.10 | 28.10 | 28.70 |
| Mass of container (g) | 18.80 | 20.90 | 21.10 |
| Mass of moisture (g) | 2.00 | 1.90 | 1.90 |
| Mass of dry soil (g) | 7.30 | 7.20 | 7.60 |
| Moisture content % | 27.40 | 26.39 | 25.00 |
| Plastic Limit % | | 26.26 | |

Table A. 20: Plastic limit for 18% PFA

| Container no. | 1 | 2 | 3 |
|---|---|---|---|
| Mass of wet soil + container (g) | 28.50 | 27.90 | 30.60 |
| Mass of dry soil + container (g) | 26.60 | 26.20 | 28.60 |
| Mass of container (g) | 19.90 | 19.30 | 20.80 |
| Mass of moisture (g) | 1.90 | 1.70 | 2.00 |
| Mass of dry soil (g) | 6.70 | 6.90 | 7.80 |
| Moisture content % | 28.36 | 24.64 | 25.64 |
| Plastic Limit % | | 26.21 | |

Table A. 21: Plastic limit for 21% PFA

| Container no. | 1 | 2 | 3 |
|---|---|---|---|
| Mass of wet soil + container (g) | 28.30 | 28.00 | 30.50 |
| Mass of dry soil + container (g) | 26.60 | 26.40 | 28.40 |
| Mass of container (g) | 19.80 | 19.70 | 19.70 |
| Mass of moisture (g) | 1.70 | 1.60 | 2.10 |
| Mass of dry soil (g) | 6.80 | 6.70 | 8.70 |
| Moisture content % | 25.00 | 23.88 | 24.14 |
| Plastic Limit % | | 24.34 | |

Table A. 22: Plastic limit for 24% PFA

| Container no. | 1 | 2 | 3 |
|---|---|---|---|
| Mass of wet soil + container (g) | 25.50 | 28.40 | 28.20 |
| Mass of dry soil + container (g) | 23.90 | 26.60 | 26.20 |
| Mass of container (g) | 18.70 | 21.00 | 19.80 |
| Mass of moisture (g) | 1.60 | 1.80 | 2.00 |
| Mass of dry soil (g) | 5.20 | 5.60 | 6.40 |
| Moisture content % | 30.77 | 32.14 | 31.25 |
| Plastic Limit % | | 31.39 | |

Table A. 23: Compaction result for 0% PFA

| Sample No | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Assume water content, w% | 9 | 12 | 15 | 18 | 21 | 24 | 27 |
| Calculated water content, w% | 9.92 | 13.96 | 17.25 | 19.26 | 20.23 | 26.18 | 29.85 |
| Mass of compacted soil and mould (g) | 8120 | 8220 | 8290 | 8370 | 8400 | 8300 | 8220 |
| wet mass of soil (g) | 1800 | 1900 | 1970 | 2050 | 2080 | 1980 | 1900 |
| Moist density, ρ(g/cm$^3$) | 1.81 | 1.91 | 1.98 | 2.06 | 2.09 | 1.99 | 1.91 |
| Dry density $\rho_d$ (g/cm$^3$) | 1.66 | 1.70 | 1.72 | 1.75 | 1.73 | 1.60 | 1.50 |

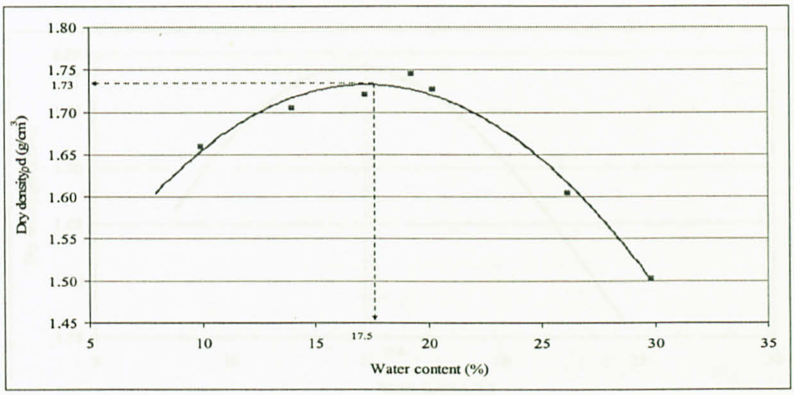



Figure A. 11: Compaction result for 0% PFA

Table A. 24: Compaction result for 9% PFA

| Sample No | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Assume water content, w% | 9 | 12 | 15 | 18 | 21 | 24 | 27 |
| Calculated water content, w% | 7.82 | 9.46 | 13.3 | 15.15 | 18.39 | 22.99 | 26.67 |
| Mass of compacted soil and mould (g) | 8170 | 8300 | 8330 | 8360 | 8390 | 8330 | 8300 |
| Wet mass of soil (g) | 1850 | 1980 | 2010 | 2040 | 2070 | 2010 | 1980 |
| Moist density, ρ(g/cm$^3$) | 1.86 | 1.99 | 2.02 | 2.05 | 2.08 | 2.02 | 1.99 |
| Dry density $\rho_d$ (g/cm$^3$) | 1.71 | 1.78 | 1.76 | 1.74 | 1.72 | 1.63 | 1.57 |

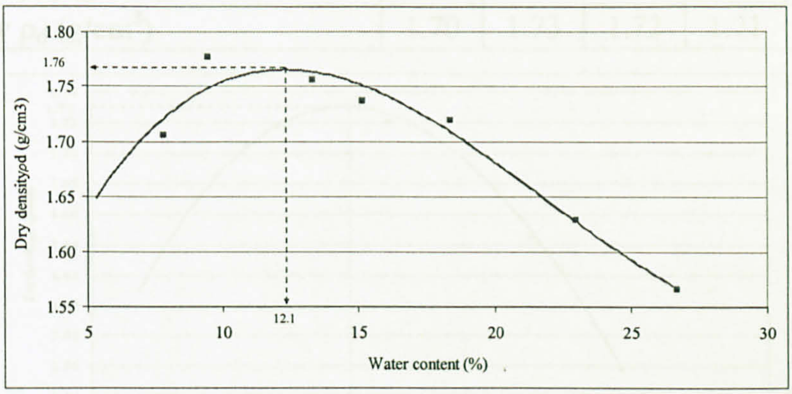



Figure A. 12: Compaction result for 9% PFA

Table A. 25: Compaction result for 12% PFA

| Sample No | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Assume water content, w% | 12 | 15 | 18 | 21 | 24 | 27 |
| Calculated water content, w% | 8.96 | 12.48 | 15.06 | 18.51 | 21.61 | 24.38 |
| Mass of compacted soil and mould (g) | 8210 | 8350 | 8420 | 8420 | 8370 | 8300 |
| Wet mass of soil (g) | 1890 | 2030 | 2100 | 2100 | 2050 | 1980 |
| Moist density, $\rho(g/cm^3)$ | 1.90 | 2.04 | 2.11 | 2.11 | 2.06 | 1.99 |
| Dry density $\rho_d$ $(g/cm^3)$ | 1.70 | 1.77 | 1.79 | 1.74 | 1.66 | 1.57 |

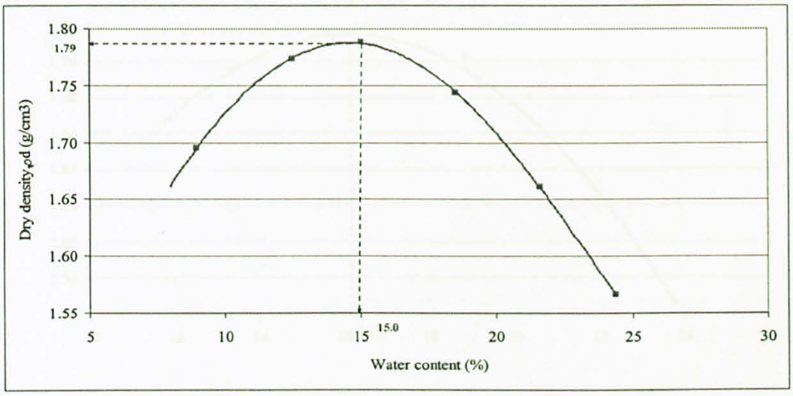



Figure A. 13: Compaction result for 12% PFA

Table A. 26: Compaction result for 15% PFA

| Sample No | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Assume water content, w% | 12 | 15 | 18 | 21 | 24 | 27 |
| Calculated water content, w% | 10.76 | 13.62 | 16.03 | 18.41 | 21.2 | 24.59 |
| Mass of compacted soil and mould (g) | 8220 | 8300 | 8340 | 8380 | 8350 | 8290 |
| Wet mass of soil (g) | 1900 | 1980 | 2020 | 2060 | 2030 | 1970 |
| Moist density, $\rho(g/cm^3)$ | 1.91 | 1.99 | 2.03 | 2.07 | 2.04 | 1.98 |
| Dry density $\rho_d$ $(g/cm^3)$ | 1.70 | 1.73 | 1.72 | 1.71 | 1.64 | 1.56 |

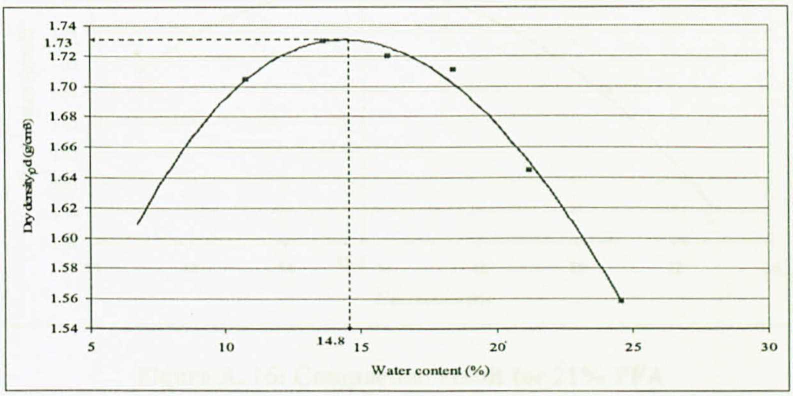



Figure A. 14: Compaction result for 15% PFA

Table A. 27: Compaction result for 18% PFA

| Sample No | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Assume water content, w% | 15 | 18 | 21 | 24 | 27 |
| Calculated water content, w% | 13.31 | 15.74 | 18.89 | 20.8 | 23.77 |
| Mass of compacted soil and mould (g) | 8260 | 8330 | 8370 | 8360 | 8300 |
| Wet mass of soil (g) | 1940 | 2010 | 2050 | 2040 | 1980 |
| Moist density, ρ(g/cm³) | 1.95 | 2.02 | 2.06 | 2.05 | 1.99 |
| Dry density $\rho_d$ (g/cm³) | 1.69 | 1.71 | 1.70 | 1.65 | 1.57 |

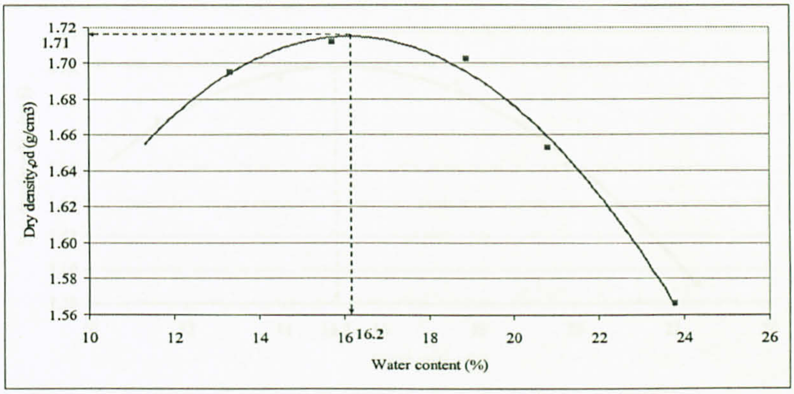



Figure A. 15: Compaction result for 18% PFA

Table A. 28: Compaction result for 21% PFA

| Sample No | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Assume water content, w% | 12 | 15 | 18 | 21 | 24 | 27 |
| Calculated water content, w% | 10.96 | 13.43 | 15.48 | 19.96 | 20.69 | 22.73 |
| Mass of compacted soil and mould (g) | 8210 | 8270 | 8360 | 8370 | 8380 | 8320 |
| Wet mass of soil (g) | 1890 | 1950 | 2040 | 2050 | 2060 | 2000 |
| Moist density, ρ(g/cm³) | 1.90 | 1.96 | 2.05 | 2.06 | 2.07 | 2.01 |
| Dry density $\rho_d$ (g/cm³) | 1.70 | 1.70 | 1.74 | 1.70 | 1.67 | 1.58 |

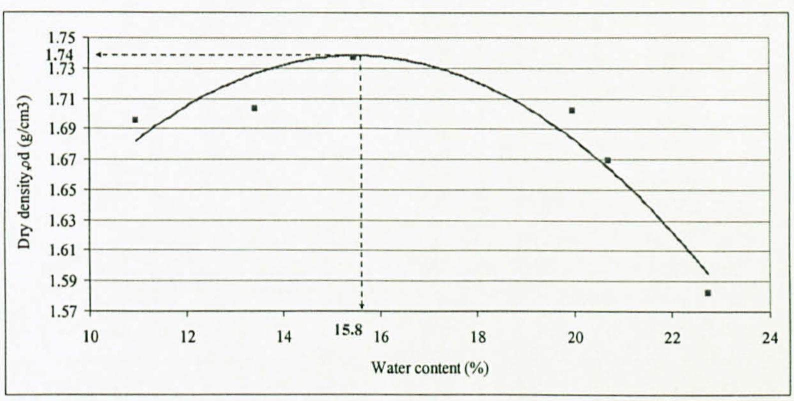



Figure A. 16: Compaction result for 21% PFA

**Table A. 29: Compaction result for 24% PFA**

| Sample No | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Assume water content, w% | 12 | 15 | 18 | 21 | 24 | 27 |
| Calculated water content, w% | 11.42 | 13.91 | 15.41 | 17.61 | 19.85 | 22.55 |
| Mass of compacted soil and mould (g) | 8200 | 8280 | 8340 | 8380 | 8370 | 8330 |
| Wet mass of soil (g) | 1880 | 1960 | 2020 | 2060 | 2050 | 2010 |
| Moist density, $\rho$(g/cm$^3$) | 1.89 | 1.97 | 2.03 | 2.07 | 2.06 | 2.02 |
| Dry density $\rho_d$ (g/cm$^3$) | 1.69 | 1.71 | 1.72 | 1.71 | 1.66 | 1.59 |

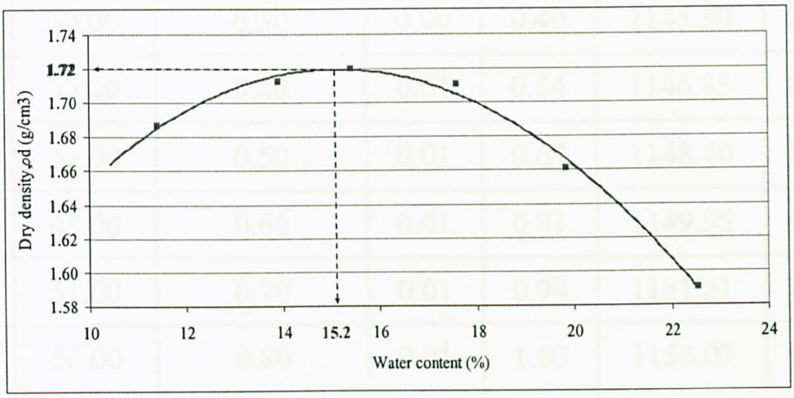



**Figure A. 17: Compaction result for 24% PFA**

**Table A. 30: Unconfined compression test for 0% of PFA (immediate test)**

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1140.69 | 0.00 | 0.00 |
| 10 | 18.00 | 0.10 | 0.00 | 0.13 | 1142.22 | 0.03 | 22.11 |
| 20 | 24.00 | 0.20 | 0.00 | 0.27 | 1143.76 | 0.03 | 29.44 |
| 30 | 30.00 | 0.30 | 0.00 | 0.40 | 1145.30 | 0.04 | 36.75 |
| 40 | 36.00 | 0.40 | 0.01 | 0.54 | 1146.85 | 0.05 | 44.04 |
| 50 | 39.00 | 0.50 | 0.01 | 0.67 | 1148.40 | 0.05 | 47.65 |
| 60 | 45.00 | 0.60 | 0.01 | 0.81 | 1149.95 | 0.06 | 54.90 |
| 70 | 51.00 | 0.70 | 0.01 | 0.94 | 1151.51 | 0.07 | 62.14 |
| 80 | 56.00 | 0.80 | 0.01 | 1.07 | 1153.07 | 0.08 | 68.14 |
| 90 | 61.00 | 0.90 | 0.01 | 1.21 | 1154.64 | 0.09 | 74.12 |
| 100 | 66.00 | 1.00 | 0.01 | 1.34 | 1156.21 | 0.09 | 80.09 |
| 110 | 70.00 | 1.10 | 0.01 | 1.48 | 1157.79 | 0.10 | 84.82 |
| 120 | 74.00 | 1.20 | 0.02 | 1.61 | 1159.36 | 0.10 | 89.55 |
| 130 | 78.00 | 1.30 | 0.02 | 1.74 | 1160.95 | 0.11 | 94.26 |
| 140 | 81.00 | 1.40 | 0.02 | 1.88 | 1162.54 | 0.11 | 97.75 |
| 150 | 84.00 | 1.50 | 0.02 | 2.01 | 1164.13 | 0.12 | 101.23 |
| 160 | 88.00 | 1.60 | 0.02 | 2.15 | 1165.73 | 0.12 | 105.91 |
| 170 | 90.00 | 1.70 | 0.02 | 2.28 | 1167.33 | 0.13 | 108.17 |
| 180 | 92.00 | 1.80 | 0.02 | 2.42 | 1168.93 | 0.13 | 110.42 |
| 190 | 94.00 | 1.90 | 0.03 | 2.55 | 1170.54 | 0.13 | 112.66 |
| 200 | 101.00 | 2.00 | 0.03 | 2.68 | 1172.16 | 0.14 | 120.89 |
| 210 | 104.00 | 2.10 | 0.03 | 2.82 | 1173.78 | 0.15 | 124.31 |
| 220 | 106.00 | 2.20 | 0.03 | 2.95 | 1175.40 | 0.15 | 126.52 |
| 230 | 108.00 | 2.30 | 0.03 | 3.09 | 1177.03 | 0.15 | 128.73 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 240 | 110.00 | 2.40 | 0.03 | 3.22 | 1178.66 | 0.15 | 130.93 |
| 250 | 112.00 | 2.50 | 0.03 | 3.36 | 1180.30 | 0.16 | 133.13 |
| 280 | 118.00 | 2.80 | 0.04 | 3.76 | 1185.24 | 0.17 | 139.68 |
| 300 | 123.00 | 3.00 | 0.04 | 4.03 | 1188.55 | 0.17 | 145.19 |
| 320 | 127.00 | 3.20 | 0.04 | 4.30 | 1191.89 | 0.18 | 149.49 |
| 340 | 133.00 | 3.40 | 0.05 | 4.56 | 1195.24 | 0.19 | 156.11 |
| 360 | 143.00 | 3.60 | 0.05 | 4.83 | 1198.61 | 0.20 | 167.38 |
| 380 | 147.00 | 3.80 | 0.05 | 5.10 | 1202.00 | 0.21 | 171.58 |
| 400 | 152.00 | 4.00 | 0.05 | 5.37 | 1205.41 | 0.21 | 176.91 |
| 420 | 157.00 | 4.20 | 0.06 | 5.64 | 1208.84 | 0.22 | 182.21 |
| 440 | 161.00 | 4.40 | 0.06 | 5.91 | 1212.29 | 0.23 | 186.32 |
| 460 | 166.00 | 4.60 | 0.06 | 6.17 | 1215.76 | 0.23 | 191.56 |
| 480 | 170.00 | 4.80 | 0.06 | 6.44 | 1219.25 | 0.24 | 195.62 |
| 500 | 174.00 | 5.00 | 0.07 | 6.71 | 1222.75 | 0.24 | 199.64 |
| 520 | 179.00 | 5.20 | 0.07 | 6.98 | 1226.28 | 0.25 | 204.79 |
| 540 | 183.00 | 5.40 | 0.07 | 7.25 | 1229.83 | 0.26 | 208.76 |
| 560 | 186.00 | 5.60 | 0.08 | 7.52 | 1233.40 | 0.26 | 211.57 |
| 580 | 191.00 | 5.80 | 0.08 | 7.79 | 1236.99 | 0.27 | 216.63 |
| 600 | 195.00 | 6.00 | 0.08 | 8.05 | 1240.60 | 0.27 | 220.52 |
| 620 | 200.00 | 6.20 | 0.08 | 8.32 | 1244.24 | 0.28 | 225.51 |
| 640 | 204.00 | 6.40 | 0.09 | 8.59 | 1247.89 | 0.29 | 229.35 |
| 660 | 207.00 | 6.60 | 0.09 | 8.86 | 1251.57 | 0.29 | 232.04 |
| 680 | 210.00 | 6.80 | 0.09 | 9.13 | 1255.26 | 0.29 | 234.71 |
| 700 | 214.00 | 7.00 | 0.09 | 9.40 | 1258.98 | 0.30 | 238.47 |
| 720 | 214.00 | 7.20 | 0.10 | 9.66 | 1262.73 | 0.30 | 237.77 |
| 740 | 220.00 | 7.40 | 0.10 | 9.93 | 1266.49 | 0.31 | 243.71 |
| 760 | 222.00 | 7.60 | 0.10 | 10.20 | 1270.28 | 0.31 | 245.19 |
| 780 | 224.00 | 7.80 | 0.10 | 10.47 | 1274.08 | 0.31 | 246.66 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 800 | 226.00 | 8.00 | 0.11 | 10.74 | 1277.92 | 0.32 | 248.11 |
| 820 | 226.00 | 8.20 | 0.11 | 11.01 | 1281.77 | 0.32 | 247.37 |
| 840 | 226.00 | 8.40 | 0.11 | 11.28 | 1285.65 | 0.32 | 246.62 |
| 860 | 225.00 | 8.60 | 0.12 | 11.54 | 1289.55 | 0.32 | 244.79 |
| 880 | 222.00 | 8.80 | 0.12 | 11.81 | 1293.48 | 0.31 | 240.79 |
| 900 | 219.00 | 9.00 | 0.12 | 12.08 | 1297.43 | 0.31 | 236.81 |
| 920 | 190.00 | 9.20 | 0.12 | 12.35 | 1301.40 | 0.27 | 204.83 |

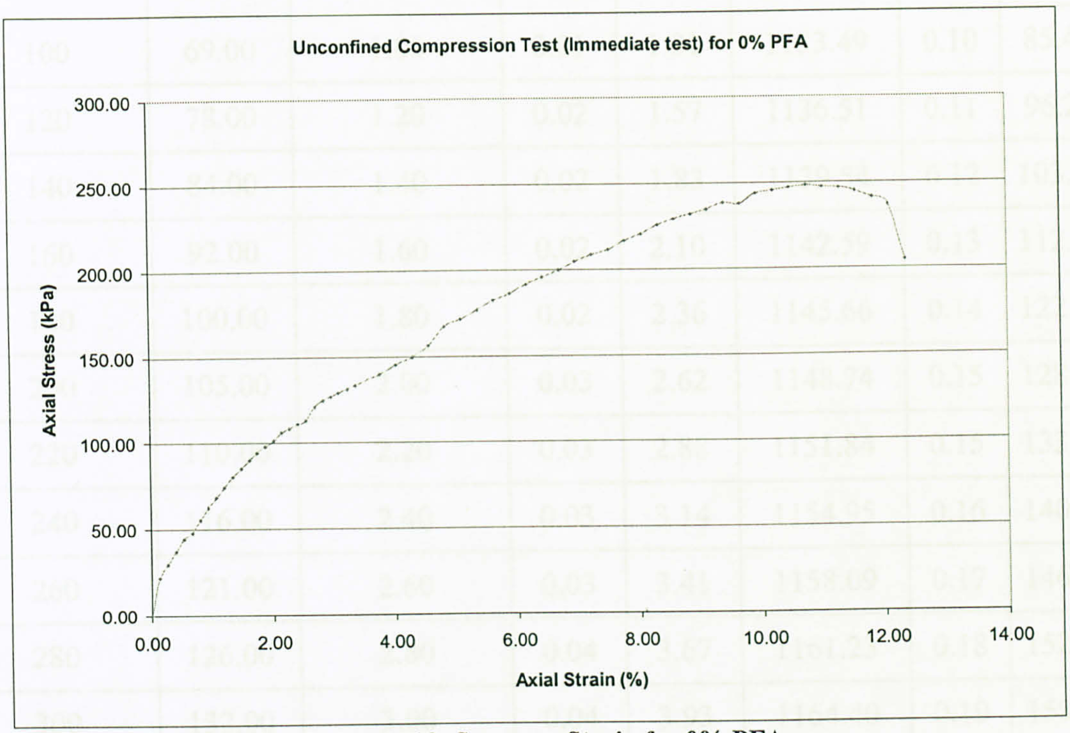



**Figure A. 18: Stress vs. Strain for 0% PFA**

Table A. 31: Unconfined compression test for 9% of PFA (immediate test)

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1118.65 | 0.00 | 0.00 |
| 10 | 15.00 | 0.10 | 0.00 | 0.13 | 1120.12 | 0.02 | 18.79 |
| 20 | 26.00 | 0.20 | 0.00 | 0.26 | 1121.59 | 0.04 | 32.52 |
| 40 | 38.00 | 0.40 | 0.01 | 0.52 | 1124.54 | 0.05 | 47.41 |
| 60 | 49.00 | 0.60 | 0.01 | 0.79 | 1127.51 | 0.07 | 60.97 |
| 80 | 58.00 | 0.80 | 0.01 | 1.05 | 1130.49 | 0.08 | 71.98 |
| 100 | 69.00 | 1.00 | 0.01 | 1.31 | 1133.49 | 0.10 | 85.40 |
| 120 | 78.00 | 1.20 | 0.02 | 1.57 | 1136.51 | 0.11 | 96.29 |
| 140 | 84.00 | 1.40 | 0.02 | 1.83 | 1139.54 | 0.12 | 103.42 |
| 160 | 92.00 | 1.60 | 0.02 | 2.10 | 1142.59 | 0.13 | 112.96 |
| 180 | 100.00 | 1.80 | 0.02 | 2.36 | 1145.66 | 0.14 | 122.46 |
| 200 | 105.00 | 2.00 | 0.03 | 2.62 | 1148.74 | 0.15 | 128.24 |
| 220 | 110.00 | 2.20 | 0.03 | 2.88 | 1151.84 | 0.15 | 133.98 |
| 240 | 116.00 | 2.40 | 0.03 | 3.14 | 1154.95 | 0.16 | 140.91 |
| 260 | 121.00 | 2.60 | 0.03 | 3.41 | 1158.09 | 0.17 | 146.59 |
| 280 | 126.00 | 2.80 | 0.04 | 3.67 | 1161.23 | 0.18 | 152.23 |
| 300 | 132.00 | 3.00 | 0.04 | 3.93 | 1164.40 | 0.19 | 159.04 |
| 320 | 136.00 | 3.20 | 0.04 | 4.19 | 1167.58 | 0.19 | 163.42 |
| 340 | 141.00 | 3.40 | 0.04 | 4.45 | 1170.79 | 0.20 | 168.96 |
| 360 | 146.00 | 3.60 | 0.05 | 4.72 | 1174.00 | 0.20 | 174.47 |
| 380 | 151.00 | 3.80 | 0.05 | 4.98 | 1177.24 | 0.21 | 179.95 |
| 400 | 155.00 | 4.00 | 0.05 | 5.24 | 1180.50 | 0.22 | 184.21 |
| 420 | 160.00 | 4.20 | 0.06 | 5.50 | 1183.77 | 0.22 | 189.63 |
| 440 | 165.00 | 4.40 | 0.06 | 5.76 | 1187.06 | 0.23 | 195.01 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 460 | 169.00 | 4.60 | 0.06 | 6.02 | 1190.37 | 0.24 | 199.18 |
| 480 | 173.00 | 4.80 | 0.06 | 6.29 | 1193.69 | 0.24 | 203.33 |
| 500 | 177.00 | 5.00 | 0.07 | 6.55 | 1197.04 | 0.25 | 207.45 |
| 520 | 181.00 | 5.20 | 0.07 | 6.81 | 1200.41 | 0.25 | 211.54 |
| 540 | 186.00 | 5.40 | 0.07 | 7.07 | 1203.79 | 0.26 | 216.77 |
| 560 | 190.00 | 5.60 | 0.07 | 7.33 | 1207.19 | 0.27 | 220.81 |
| 580 | 195.00 | 5.80 | 0.08 | 7.60 | 1210.61 | 0.27 | 225.98 |
| 600 | 208.00 | 6.00 | 0.08 | 7.86 | 1214.06 | 0.29 | 240.36 |
| 620 | 202.00 | 6.20 | 0.08 | 8.12 | 1217.52 | 0.28 | 232.77 |
| 640 | 206.00 | 6.40 | 0.08 | 8.38 | 1221.00 | 0.29 | 236.70 |
| 660 | 210.00 | 6.60 | 0.09 | 8.64 | 1224.50 | 0.29 | 240.61 |
| 680 | 215.00 | 6.80 | 0.09 | 8.91 | 1228.02 | 0.30 | 245.63 |
| 700 | 217.00 | 7.00 | 0.09 | 9.17 | 1231.56 | 0.30 | 247.20 |
| 720 | 221.00 | 7.20 | 0.09 | 9.43 | 1235.12 | 0.31 | 251.03 |
| 740 | 225.00 | 7.40 | 0.10 | 9.69 | 1238.71 | 0.32 | 254.84 |
| 760 | 228.00 | 7.60 | 0.10 | 9.95 | 1242.31 | 0.32 | 257.48 |
| 780 | 232.00 | 7.80 | 0.10 | 10.22 | 1245.93 | 0.33 | 261.24 |
| 800 | 236.00 | 8.00 | 0.10 | 10.48 | 1249.58 | 0.33 | 264.97 |
| 820 | 240.00 | 8.20 | 0.11 | 10.74 | 1253.25 | 0.34 | 268.67 |
| 840 | 242.00 | 8.40 | 0.11 | 11.00 | 1256.94 | 0.34 | 270.11 |
| 860 | 246.00 | 8.60 | 0.11 | 11.26 | 1260.65 | 0.35 | 273.77 |
| 880 | 250.00 | 8.80 | 0.12 | 11.53 | 1264.38 | 0.35 | 277.40 |
| 900 | 251.00 | 9.00 | 0.12 | 11.79 | 1268.13 | 0.35 | 277.69 |
| 920 | 254.00 | 9.20 | 0.12 | 12.05 | 1271.91 | 0.36 | 280.17 |
| 940 | 257.00 | 9.40 | 0.12 | 12.31 | 1275.71 | 0.36 | 282.64 |
| 960 | 259.00 | 9.60 | 0.13 | 12.57 | 1279.53 | 0.36 | 283.98 |
| 980 | 261.00 | 9.80 | 0.13 | 12.84 | 1283.38 | 0.37 | 285.32 |
| 1000 | 262.00 | 10.00 | 0.13 | 13.10 | 1287.25 | 0.37 | 285.55 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1020 | 262.00 | 10.20 | 0.13 | 13.36 | 1291.14 | 0.37 | 284.69 |
| 1040 | 263.00 | 10.40 | 0.14 | 13.62 | 1295.05 | 0.37 | 284.91 |
| 1060 | 263.00 | 10.60 | 0.14 | 13.88 | 1298.99 | 0.37 | 284.05 |
| 1080 | 263.00 | 10.80 | 0.14 | 14.15 | 1302.96 | 0.37 | 283.19 |
| 1100 | 262.00 | 11.00 | 0.14 | 14.41 | 1306.94 | 0.37 | 281.25 |
| 1120 | 259.00 | 11.20 | 0.15 | 14.67 | 1310.96 | 0.36 | 277.18 |
| 1140 | 242.00 | 11.40 | 0.15 | 14.93 | 1314.99 | 0.34 | 258.19 |

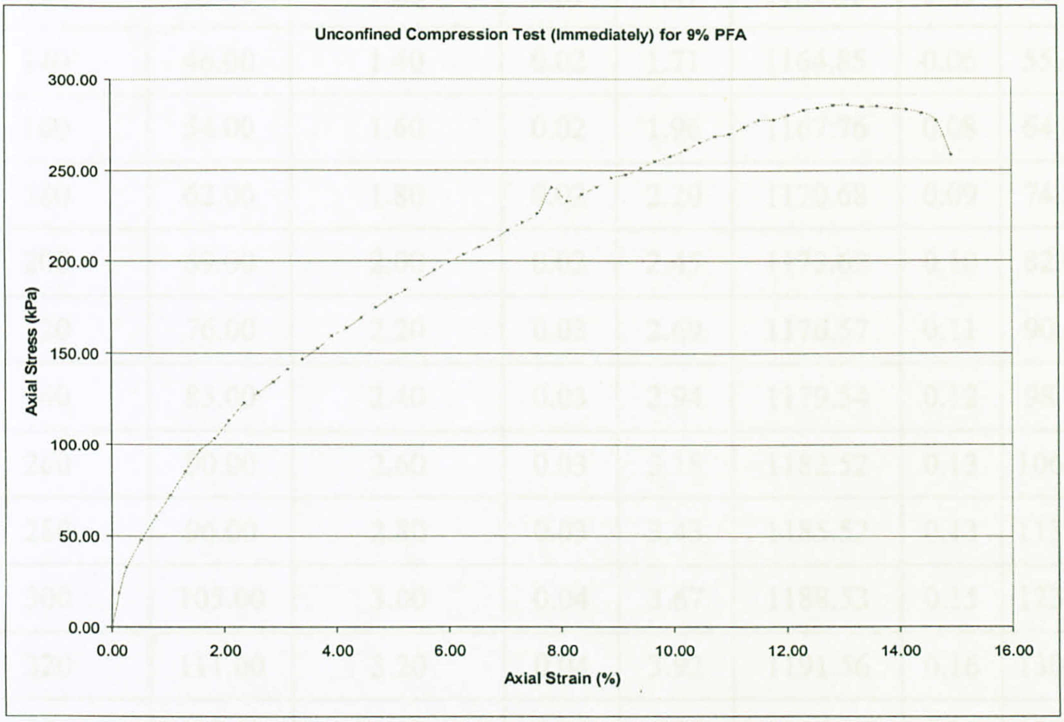



**Figure A. 19: Stress vs. Strain for 9% PFA (immediate test)**

**Table A. 32: Unconfined compression test for 12% of PFA (immediate test)**

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1144.88 | 0.00 | 0.00 |
| 20 | 0.00 | 0.20 | 0.00 | 0.24 | 1147.69 | 0.00 | 0.00 |
| 40 | 2.00 | 0.40 | 0.00 | 0.49 | 1150.52 | 0.00 | 2.44 |
| 60 | 10.00 | 0.60 | 0.01 | 0.73 | 1153.36 | 0.01 | 12.16 |
| 80 | 19.00 | 0.80 | 0.01 | 0.98 | 1156.21 | 0.03 | 23.05 |
| 100 | 28.00 | 1.00 | 0.01 | 1.22 | 1159.07 | 0.04 | 33.89 |
| 120 | 37.00 | 1.20 | 0.01 | 1.47 | 1161.95 | 0.05 | 44.67 |
| 140 | 46.00 | 1.40 | 0.02 | 1.71 | 1164.85 | 0.06 | 55.40 |
| 160 | 54.00 | 1.60 | 0.02 | 1.96 | 1167.76 | 0.08 | 64.88 |
| 180 | 62.00 | 1.80 | 0.02 | 2.20 | 1170.68 | 0.09 | 74.30 |
| 200 | 69.00 | 2.00 | 0.02 | 2.45 | 1173.62 | 0.10 | 82.48 |
| 220 | 76.00 | 2.20 | 0.03 | 2.69 | 1176.57 | 0.11 | 90.62 |
| 240 | 83.00 | 2.40 | 0.03 | 2.94 | 1179.54 | 0.12 | 98.72 |
| 260 | 90.00 | 2.60 | 0.03 | 3.18 | 1182.52 | 0.13 | 106.78 |
| 280 | 96.00 | 2.80 | 0.03 | 3.43 | 1185.52 | 0.13 | 113.61 |
| 300 | 105.00 | 3.00 | 0.04 | 3.67 | 1188.53 | 0.15 | 123.94 |
| 320 | 111.00 | 3.20 | 0.04 | 3.92 | 1191.56 | 0.16 | 130.69 |
| 340 | 118.00 | 3.40 | 0.04 | 4.16 | 1194.61 | 0.17 | 138.58 |
| 360 | 125.00 | 3.60 | 0.04 | 4.41 | 1197.66 | 0.18 | 146.43 |
| 380 | 133.00 | 3.80 | 0.05 | 4.65 | 1200.74 | 0.19 | 155.40 |
| 400 | 141.00 | 4.00 | 0.05 | 4.90 | 1203.83 | 0.20 | 164.32 |
| 420 | 147.00 | 4.20 | 0.05 | 5.14 | 1206.94 | 0.21 | 170.87 |
| 440 | 154.00 | 4.40 | 0.05 | 5.39 | 1210.06 | 0.22 | 178.55 |
| 460 | 162.00 | 4.60 | 0.06 | 5.63 | 1213.20 | 0.23 | 187.34 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 480 | 169.00 | 4.80 | 0.06 | 5.88 | 1216.36 | 0.24 | 194.93 |
| 500 | 178.00 | 5.00 | 0.06 | 6.12 | 1219.53 | 0.25 | 204.77 |
| 520 | 185.00 | 5.20 | 0.06 | 6.37 | 1222.72 | 0.26 | 212.27 |
| 540 | 189.00 | 5.40 | 0.07 | 6.61 | 1225.92 | 0.27 | 216.29 |
| 560 | 195.00 | 5.60 | 0.07 | 6.86 | 1229.14 | 0.27 | 222.58 |
| 580 | 203.00 | 5.80 | 0.07 | 7.10 | 1232.38 | 0.28 | 231.10 |
| 600 | 209.00 | 6.00 | 0.07 | 7.34 | 1235.64 | 0.29 | 237.30 |
| 620 | 217.00 | 6.20 | 0.08 | 7.59 | 1238.91 | 0.30 | 245.73 |
| 640 | 223.00 | 6.40 | 0.08 | 7.83 | 1242.21 | 0.31 | 251.86 |
| 660 | 230.00 | 6.60 | 0.08 | 8.08 | 1245.51 | 0.32 | 259.07 |
| 680 | 236.00 | 6.80 | 0.08 | 8.32 | 1248.84 | 0.33 | 265.13 |
| 700 | 242.00 | 7.00 | 0.09 | 8.57 | 1252.18 | 0.34 | 271.14 |
| 720 | 248.00 | 7.20 | 0.09 | 8.81 | 1255.55 | 0.35 | 277.12 |
| 740 | 253.00 | 7.40 | 0.09 | 9.06 | 1258.93 | 0.35 | 281.95 |
| 760 | 258.00 | 7.60 | 0.09 | 9.30 | 1262.32 | 0.36 | 286.74 |
| 780 | 262.00 | 7.80 | 0.10 | 9.55 | 1265.74 | 0.37 | 290.40 |
| 800 | 266.00 | 8.00 | 0.10 | 9.79 | 1269.18 | 0.37 | 294.04 |
| 820 | 269.00 | 8.20 | 0.10 | 10.04 | 1272.63 | 0.38 | 296.55 |
| 840 | 271.00 | 8.40 | 0.10 | 10.28 | 1276.10 | 0.38 | 297.94 |
| 860 | 271.00 | 8.60 | 0.11 | 10.53 | 1279.60 | 0.38 | 297.13 |
| 880 | 250.00 | 8.80 | 0.11 | 10.77 | 1283.11 | 0.35 | 273.35 |

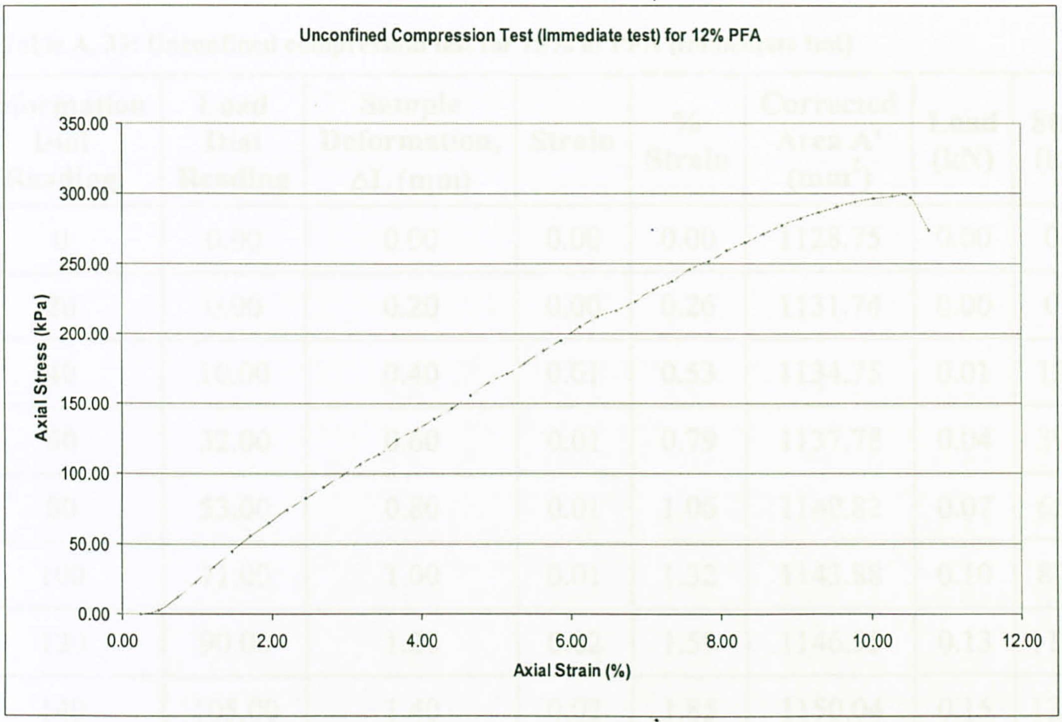



**Figure A. 20: Stress vs. Strain for 12% PFA (immediate test)**

**Table A. 33: Unconfined compression test for 15% of PFA (immediate test)**

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1128.75 | 0.00 | 0.00 |
| 20 | 0.00 | 0.20 | 0.00 | 0.26 | 1131.74 | 0.00 | 0.00 |
| 40 | 10.00 | 0.40 | 0.01 | 0.53 | 1134.75 | 0.01 | 12.36 |
| 60 | 32.00 | 0.60 | 0.01 | 0.79 | 1137.78 | 0.04 | 39.46 |
| 80 | 53.00 | 0.80 | 0.01 | 1.06 | 1140.82 | 0.07 | 65.18 |
| 100 | 71.00 | 1.00 | 0.01 | 1.32 | 1143.88 | 0.10 | 87.08 |
| 120 | 90.00 | 1.20 | 0.02 | 1.59 | 1146.95 | 0.13 | 110.09 |
| 140 | 105.00 | 1.40 | 0.02 | 1.85 | 1150.04 | 0.15 | 128.09 |
| 160 | 120.00 | 1.60 | 0.02 | 2.12 | 1153.15 | 0.17 | 146.00 |
| 180 | 134.00 | 1.80 | 0.02 | 2.38 | 1156.27 | 0.19 | 162.59 |
| 200 | 146.00 | 2.00 | 0.03 | 2.64 | 1159.41 | 0.20 | 176.67 |
| 220 | 158.00 | 2.20 | 0.03 | 2.91 | 1162.57 | 0.22 | 190.67 |
| 240 | 170.00 | 2.40 | 0.03 | 3.17 | 1165.75 | 0.24 | 204.59 |
| 260 | 180.00 | 2.60 | 0.03 | 3.44 | 1168.94 | 0.25 | 216.04 |
| 280 | 190.00 | 2.80 | 0.04 | 3.70 | 1172.15 | 0.27 | 227.41 |
| 300 | 200.00 | 3.00 | 0.04 | 3.97 | 1175.38 | 0.28 | 238.73 |
| 320 | 210.00 | 3.20 | 0.04 | 4.23 | 1178.62 | 0.29 | 249.97 |
| 340 | 220.00 | 3.40 | 0.04 | 4.50 | 1181.89 | 0.31 | 261.15 |
| 360 | 230.00 | 3.60 | 0.05 | 4.76 | 1185.17 | 0.32 | 272.27 |
| 380 | 241.00 | 3.80 | 0.05 | 5.03 | 1188.47 | 0.34 | 284.49 |
| 400 | 250.00 | 4.00 | 0.05 | 5.29 | 1191.79 | 0.35 | 294.30 |
| 420 | 260.00 | 4.20 | 0.06 | 5.55 | 1195.13 | 0.36 | 305.21 |
| 440 | 270.00 | 4.40 | 0.06 | 5.82 | 1198.48 | 0.38 | 316.07 |
| 460 | 279.00 | 4.60 | 0.06 | 6.08 | 1201.86 | 0.39 | 325.68 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 480 | 288.00 | 4.80 | 0.06 | 6.35 | 1205.25 | 0.40 | 335.24 |
| 500 | 295.00 | 5.00 | 0.07 | 6.61 | 1208.67 | 0.41 | 342.42 |
| 520 | 303.00 | 5.20 | 0.07 | 6.88 | 1212.10 | 0.43 | 350.71 |
| 540 | 311.00 | 5.40 | 0.07 | 7.14 | 1215.55 | 0.44 | 358.95 |
| 560 | 318.00 | 5.60 | 0.07 | 7.41 | 1219.02 | 0.45 | 365.98 |
| 580 | 325.00 | 5.80 | 0.08 | 7.67 | 1222.52 | 0.46 | 372.97 |
| 600 | 331.00 | 6.00 | 0.08 | 7.93 | 1226.03 | 0.46 | 378.77 |
| 620 | 337.00 | 6.20 | 0.08 | 8.20 | 1229.56 | 0.47 | 384.53 |
| 640 | 342.00 | 6.40 | 0.08 | 8.46 | 1233.11 | 0.48 | 389.11 |
| 660 | 345.00 | 6.60 | 0.09 | 8.73 | 1236.69 | 0.48 | 391.39 |
| 680 | 346.00 | 6.80 | 0.09 | 8.99 | 1240.28 | 0.49 | 391.38 |
| 700 | 345.00 | 7.00 | 0.09 | 9.26 | 1243.89 | 0.48 | 389.12 |
| 720 | 340.00 | 7.20 | 0.10 | 9.52 | 1247.53 | 0.48 | 382.36 |
| 740 | 327.00 | 7.40 | 0.10 | 9.79 | 1251.19 | 0.46 | 366.67 |

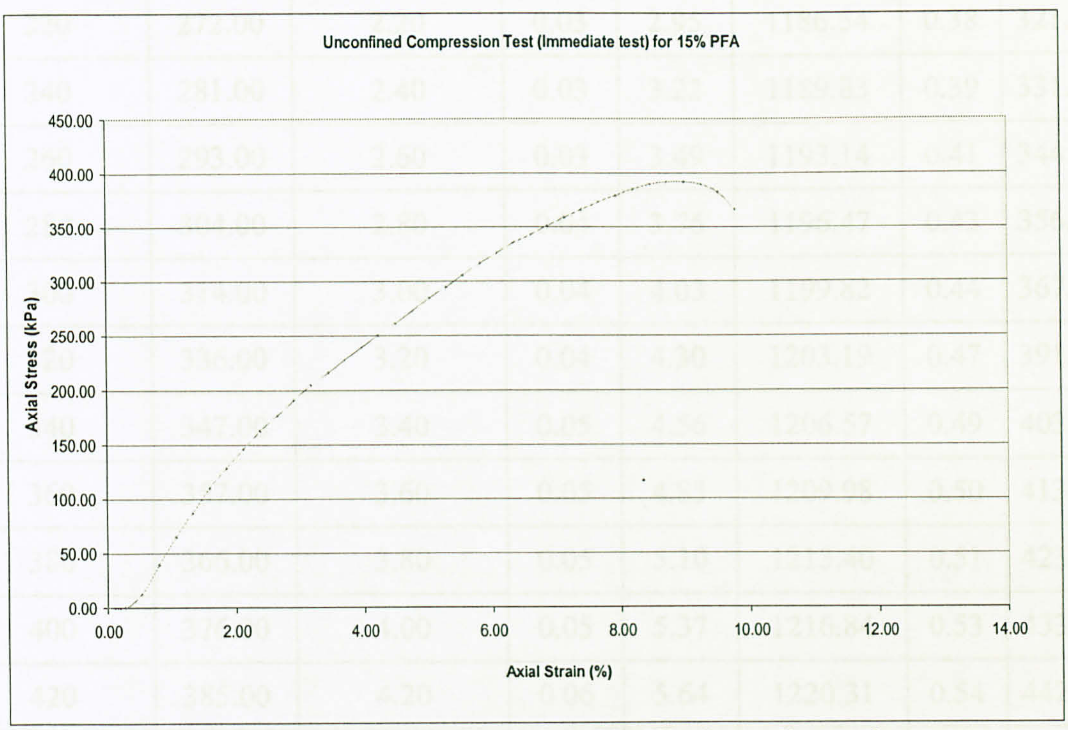



**Figure A. 21: Stress vs. Strain for 15% PFA (immediate test)**

Table A. 34: Unconfined compression test for 18% of PFA (immediate test)

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1151.49 | 0.00 | 0.00 |
| 10 | 26.00 | 0.10 | 0.00 | 0.13 | 1153.04 | 0.04 | 31.64 |
| 20 | 43.00 | 0.20 | 0.00 | 0.27 | 1154.59 | 0.06 | 52.25 |
| 40 | 72.00 | 0.40 | 0.01 | 0.54 | 1157.71 | 0.10 | 87.25 |
| 60 | 110.00 | 0.60 | 0.01 | 0.81 | 1160.84 | 0.15 | 132.94 |
| 80 | 145.00 | 0.80 | 0.01 | 1.07 | 1163.99 | 0.20 | 174.77 |
| 100 | 177.00 | 1.00 | 0.01 | 1.34 | 1167.16 | 0.25 | 212.76 |
| 120 | 202.00 | 1.20 | 0.02 | 1.61 | 1170.35 | 0.28 | 242.15 |
| 140 | 221.00 | 1.40 | 0.02 | 1.88 | 1173.55 | 0.31 | 264.20 |
| 160 | 236.00 | 1.60 | 0.02 | 2.15 | 1176.77 | 0.33 | 281.36 |
| 180 | 249.00 | 1.80 | 0.02 | 2.42 | 1180.01 | 0.35 | 296.05 |
| 200 | 261.00 | 2.00 | 0.03 | 2.69 | 1183.27 | 0.37 | 309.46 |
| 220 | 272.00 | 2.20 | 0.03 | 2.95 | 1186.54 | 0.38 | 321.61 |
| 240 | 281.00 | 2.40 | 0.03 | 3.22 | 1189.83 | 0.39 | 331.33 |
| 260 | 293.00 | 2.60 | 0.03 | 3.49 | 1193.14 | 0.41 | 344.53 |
| 280 | 304.00 | 2.80 | 0.04 | 3.76 | 1196.47 | 0.43 | 356.47 |
| 300 | 314.00 | 3.00 | 0.04 | 4.03 | 1199.82 | 0.44 | 367.16 |
| 320 | 336.00 | 3.20 | 0.04 | 4.30 | 1203.19 | 0.47 | 391.79 |
| 340 | 347.00 | 3.40 | 0.05 | 4.56 | 1206.57 | 0.49 | 403.48 |
| 360 | 357.00 | 3.60 | 0.05 | 4.83 | 1209.98 | 0.50 | 413.94 |
| 380 | 366.00 | 3.80 | 0.05 | 5.10 | 1213.40 | 0.51 | 423.18 |
| 400 | 376.00 | 4.00 | 0.05 | 5.37 | 1216.84 | 0.53 | 433.51 |
| 420 | 385.00 | 4.20 | 0.06 | 5.64 | 1220.31 | 0.54 | 442.63 |
| 440 | 396.00 | 4.40 | 0.06 | 5.91 | 1223.79 | 0.56 | 453.98 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 460 | 405.00 | 4.60 | 0.06 | 6.18 | 1227.29 | 0.57 | 462.97 |
| 480 | 416.00 | 4.80 | 0.06 | 6.44 | 1230.81 | 0.58 | 474.18 |
| 500 | 424.00 | 5.00 | 0.07 | 6.71 | 1234.36 | 0.59 | 481.92 |
| 520 | 436.00 | 5.20 | 0.07 | 6.98 | 1237.92 | 0.61 | 494.13 |
| 540 | 444.00 | 5.40 | 0.07 | 7.25 | 1241.50 | 0.62 | 501.74 |
| 560 | 452.00 | 5.60 | 0.08 | 7.52 | 1245.11 | 0.63 | 509.30 |
| 580 | 460.00 | 5.80 | 0.08 | 7.79 | 1248.73 | 0.65 | 516.81 |
| 600 | 468.00 | 6.00 | 0.08 | 8.06 | 1252.38 | 0.66 | 524.27 |
| 620 | 474.00 | 6.20 | 0.08 | 8.32 | 1256.05 | 0.67 | 529.44 |
| 640 | 479.00 | 6.40 | 0.09 | 8.59 | 1259.74 | 0.67 | 533.46 |
| 660 | 483.00 | 6.60 | 0.09 | 8.86 | 1263.45 | 0.68 | 536.33 |
| 680 | 485.00 | 6.80 | 0.09 | 9.13 | 1267.18 | 0.68 | 536.97 |
| 700 | 488.00 | 7.00 | 0.09 | 9.40 | 1270.94 | 0.68 | 538.69 |
| 720 | 462.00 | 7.20 | 0.10 | 9.67 | 1274.72 | 0.65 | 508.48 |

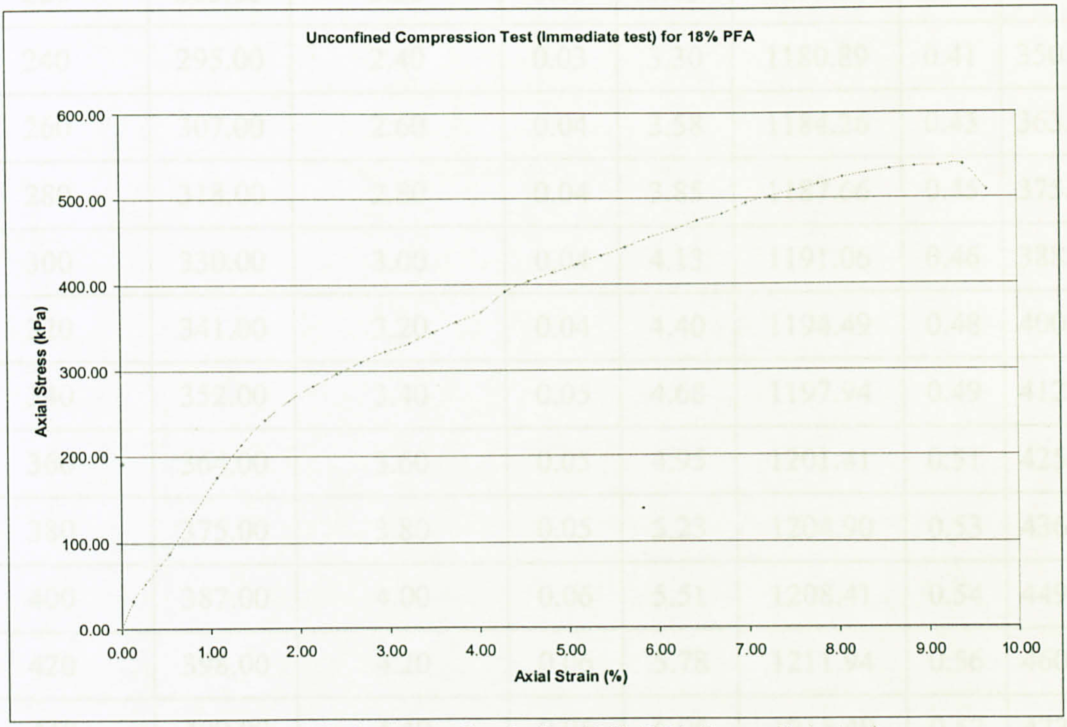



**Figure A. 22: Stress vs. Strain for 18% PFA (immediate test)**

Table A. 35: Unconfined compression test for 21% of PFA (immediate test)

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1141.89 | 0.00 | 0.00 |
| 10 | 30.00 | 0.10 | 0.00 | 0.14 | 1143.46 | 0.04 | 36.81 |
| 20 | 47.00 | 0.20 | 0.00 | 0.28 | 1145.04 | 0.07 | 57.59 |
| 40 | 82.00 | 0.40 | 0.01 | 0.55 | 1148.21 | 0.12 | 100.19 |
| 60 | 122.00 | 0.60 | 0.01 | 0.83 | 1151.40 | 0.17 | 148.66 |
| 80 | 157.00 | 0.80 | 0.01 | 1.10 | 1154.60 | 0.22 | 190.77 |
| 100 | 183.00 | 1.00 | 0.01 | 1.38 | 1157.82 | 0.26 | 221.75 |
| 120 | 207.00 | 1.20 | 0.02 | 1.65 | 1161.06 | 0.29 | 250.13 |
| 140 | 226.00 | 1.40 | 0.02 | 1.93 | 1164.32 | 0.32 | 272.32 |
| 160 | 245.00 | 1.60 | 0.02 | 2.20 | 1167.60 | 0.34 | 294.39 |
| 180 | 257.00 | 1.80 | 0.02 | 2.48 | 1170.89 | 0.36 | 307.94 |
| 200 | 271.00 | 2.00 | 0.03 | 2.75 | 1174.21 | 0.38 | 323.79 |
| 220 | 283.00 | 2.20 | 0.03 | 3.03 | 1177.54 | 0.40 | 337.18 |
| 240 | 295.00 | 2.40 | 0.03 | 3.30 | 1180.89 | 0.41 | 350.48 |
| 260 | 307.00 | 2.60 | 0.04 | 3.58 | 1184.26 | 0.43 | 363.69 |
| 280 | 318.00 | 2.80 | 0.04 | 3.85 | 1187.66 | 0.45 | 375.65 |
| 300 | 330.00 | 3.00 | 0.04 | 4.13 | 1191.06 | 0.46 | 388.71 |
| 320 | 341.00 | 3.20 | 0.04 | 4.40 | 1194.49 | 0.48 | 400.51 |
| 340 | 352.00 | 3.40 | 0.05 | 4.68 | 1197.94 | 0.49 | 412.24 |
| 360 | 364.00 | 3.60 | 0.05 | 4.95 | 1201.41 | 0.51 | 425.06 |
| 380 | 375.00 | 3.80 | 0.05 | 5.23 | 1204.90 | 0.53 | 436.64 |
| 400 | 387.00 | 4.00 | 0.06 | 5.51 | 1208.41 | 0.54 | 449.31 |
| 420 | 398.00 | 4.20 | 0.06 | 5.78 | 1211.94 | 0.56 | 460.73 |
| 440 | 409.00 | 4.40 | 0.06 | 6.06 | 1215.49 | 0.57 | 472.08 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 460 | 418.00 | 4.60 | 0.06 | 6.33 | 1219.07 | 0.59 | 481.06 |
| 480 | 427.00 | 4.80 | 0.07 | 6.61 | 1222.66 | 0.60 | 489.97 |
| 500 | 438.00 | 5.00 | 0.07 | 6.88 | 1226.27 | 0.61 | 501.11 |
| 520 | 448.00 | 5.20 | 0.07 | 7.16 | 1229.91 | 0.63 | 511.04 |
| 540 | 457.00 | 5.40 | 0.07 | 7.43 | 1233.56 | 0.64 | 519.76 |
| 560 | 467.00 | 5.60 | 0.08 | 7.71 | 1237.24 | 0.66 | 529.55 |
| 580 | 475.00 | 5.80 | 0.08 | 7.98 | 1240.94 | 0.67 | 537.02 |
| 600 | 483.00 | 6.00 | 0.08 | 8.26 | 1244.67 | 0.68 | 544.43 |
| 620 | 491.00 | 6.20 | 0.09 | 8.53 | 1248.41 | 0.69 | 551.78 |
| 640 | 497.00 | 6.40 | 0.09 | 8.81 | 1252.18 | 0.70 | 556.85 |
| 660 | 504.00 | 6.60 | 0.09 | 9.08 | 1255.97 | 0.71 | 562.98 |
| 680 | 510.00 | 6.80 | 0.09 | 9.36 | 1259.79 | 0.72 | 567.96 |
| 700 | 513.00 | 7.00 | 0.10 | 9.63 | 1263.62 | 0.72 | 569.57 |
| 720 | 516.00 | 7.20 | 0.10 | 9.91 | 1267.49 | 0.72 | 571.15 |
| 740 | 517.00 | 7.40 | 0.10 | 10.18 | 1271.37 | 0.73 | 570.51 |
| 760 | 517.00 | 7.60 | 0.10 | 10.46 | 1275.28 | 0.73 | 568.76 |
| 780 | 470.00 | 7.80 | 0.11 | 10.73 | 1279.21 | 0.66 | 515.47 |

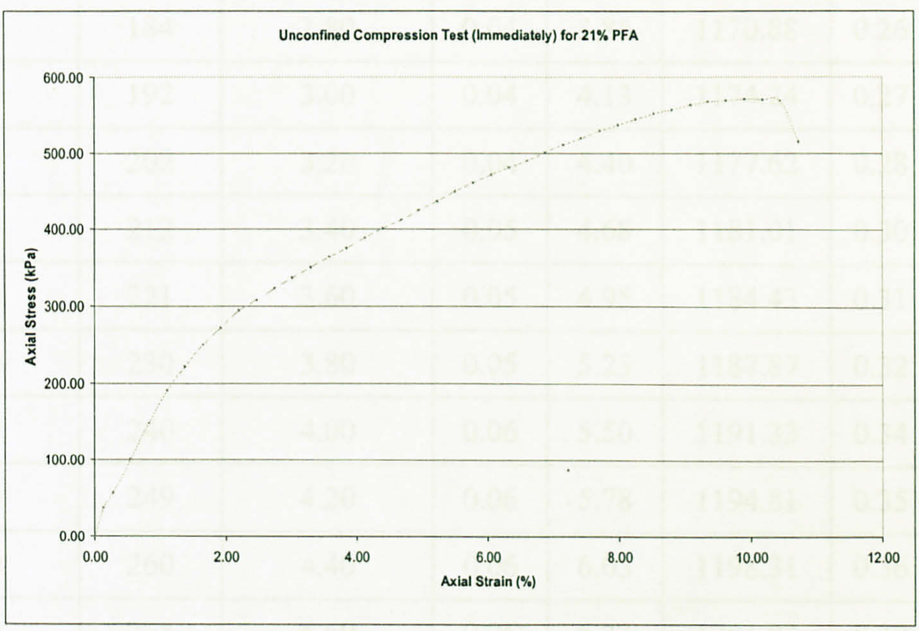



**Figure A. 23: Stress vs. Strain for 21% PFA (immediate test)**

**Table A. 36: Unconfined compression test for 24% of PFA (immediate test)**

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0.00 | 0.00 | 0.00 | 1125.77 | 0.00 | 0.00 |
| 20 | 5 | 0.20 | 0.00 | 0.28 | 1128.88 | 0.01 | 6.21 |
| 40 | 20 | 0.40 | 0.01 | 0.55 | 1132.00 | 0.03 | 24.79 |
| 60 | 45 | 0.60 | 0.01 | 0.83 | 1135.14 | 0.06 | 55.62 |
| 80 | 64 | 0.80 | 0.01 | 1.10 | 1138.30 | 0.09 | 78.88 |
| 100 | 80 | 1.00 | 0.01 | 1.38 | 1141.48 | 0.11 | 98.33 |
| 120 | 94 | 1.20 | 0.02 | 1.65 | 1144.67 | 0.13 | 115.21 |
| 140 | 105 | 1.40 | 0.02 | 1.93 | 1147.88 | 0.15 | 128.33 |
| 160 | 118 | 1.60 | 0.02 | 2.20 | 1151.11 | 0.17 | 143.82 |
| 180 | 130 | 1.80 | 0.02 | 2.48 | 1154.36 | 0.18 | 158.00 |
| 200 | 140 | 2.00 | 0.03 | 2.75 | 1157.62 | 0.20 | 169.67 |
| 220 | 151 | 2.20 | 0.03 | 3.03 | 1160.91 | 0.21 | 182.48 |
| 240 | 162 | 2.40 | 0.03 | 3.30 | 1164.21 | 0.23 | 195.22 |
| 260 | 172 | 2.60 | 0.04 | 3.58 | 1167.53 | 0.24 | 206.68 |
| 280 | 184 | 2.80 | 0.04 | 3.85 | 1170.88 | 0.26 | 220.47 |
| 300 | 192 | 3.00 | 0.04 | 4.13 | 1174.24 | 0.27 | 229.40 |
| 320 | 202 | 3.20 | 0.04 | 4.40 | 1177.62 | 0.28 | 240.65 |
| 340 | 212 | 3.40 | 0.05 | 4.68 | 1181.01 | 0.30 | 251.84 |
| 360 | 221 | 3.60 | 0.05 | 4.95 | 1184.43 | 0.31 | 261.77 |
| 380 | 230 | 3.80 | 0.05 | 5.23 | 1187.87 | 0.32 | 271.65 |
| 400 | 240 | 4.00 | 0.06 | 5.50 | 1191.33 | 0.34 | 282.63 |
| 420 | 249 | 4.20 | 0.06 | 5.78 | 1194.81 | 0.35 | 292.38 |
| 440 | 260 | 4.40 | 0.06 | 6.05 | 1198.31 | 0.36 | 304.40 |
| 460 | 268 | 4.60 | 0.06 | 6.33 | 1201.83 | 0.38 | 312.85 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 480 | 279 | 4.80 | 0.07 | 6.60 | 1205.37 | 0.39 | 324.74 |
| 500 | 286 | 5.00 | 0.07 | 6.88 | 1208.93 | 0.40 | 331.90 |
| 520 | 295 | 5.20 | 0.07 | 7.15 | 1212.51 | 0.41 | 341.34 |
| 540 | 304 | 5.40 | 0.07 | 7.43 | 1216.12 | 0.43 | 350.71 |
| 560 | 315 | 5.60 | 0.08 | 7.70 | 1219.74 | 0.44 | 362.32 |
| 580 | 320 | 5.80 | 0.08 | 7.98 | 1223.39 | 0.45 | 366.97 |
| 600 | 326 | 6.00 | 0.08 | 8.25 | 1227.06 | 0.46 | 372.73 |
| 620 | 333 | 6.20 | 0.09 | 8.53 | 1230.75 | 0.47 | 379.60 |
| 640 | 338 | 6.40 | 0.09 | 8.80 | 1234.46 | 0.47 | 384.14 |
| 660 | 342 | 6.60 | 0.09 | 9.08 | 1238.20 | 0.48 | 387.51 |
| 680 | 347 | 6.80 | 0.09 | 9.35 | 1241.96 | 0.49 | 391.98 |
| 700 | 348 | 7.00 | 0.10 | 9.63 | 1245.74 | 0.49 | 391.92 |
| 720 | 349 | 7.20 | 0.10 | 9.91 | 1249.54 | 0.49 | 391.85 |
| 740 | 345 | 7.40 | 0.10 | 10.18 | 1253.37 | 0.48 | 386.18 |
| 760 | 339 | 7.60 | 0.10 | 10.46 | 1257.22 | 0.48 | 378.30 |

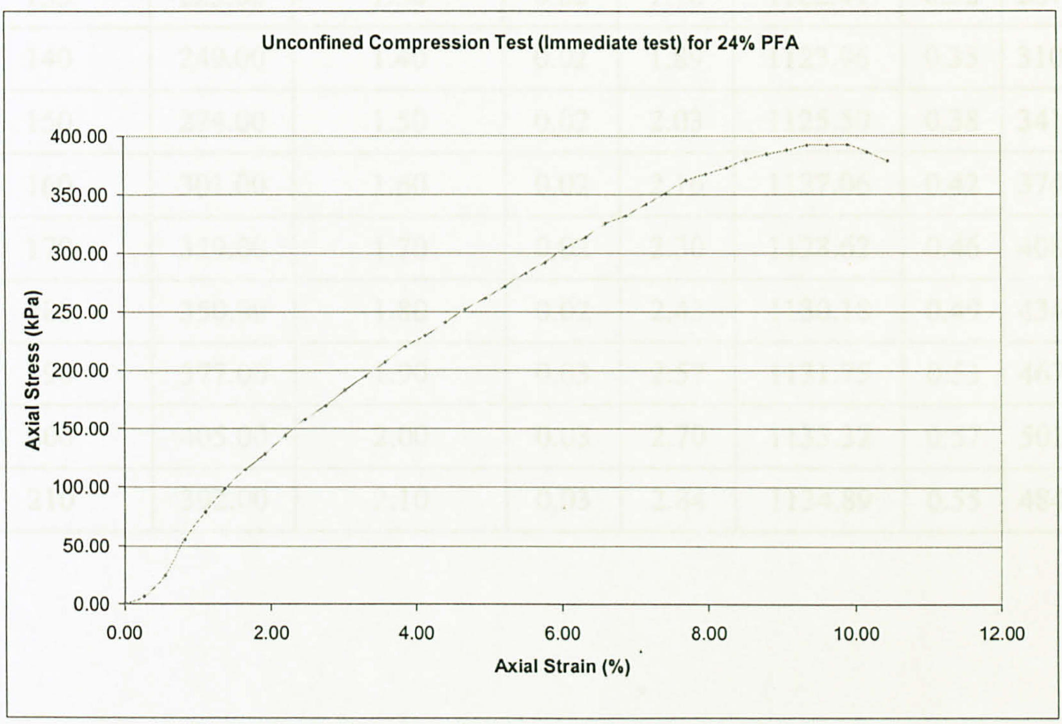



**Figure A. 24: Stress vs. Strain for 24% PFA (immediate test)**

**Table A. 37: Unconfined compression test for 0% of PFA (3 days curing)**

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1102.70 | 0.00 | 0.00 |
| 10 | 27.00 | 0.10 | 0.00 | 0.14 | 1104.19 | 0.04 | 34.31 |
| 20 | 43.00 | 0.20 | 0.00 | 0.27 | 1105.69 | 0.06 | 54.56 |
| 30 | 58.00 | 0.30 | 0.00 | 0.41 | 1107.19 | 0.08 | 73.49 |
| 40 | 72.00 | 0.40 | 0.01 | 0.54 | 1108.69 | 0.10 | 91.11 |
| 50 | 57.00 | 0.50 | 0.01 | 0.68 | 1110.20 | 0.08 | 72.03 |
| 60 | 78.00 | 0.60 | 0.01 | 0.81 | 1111.71 | 0.11 | 98.43 |
| 70 | 100.00 | 0.70 | 0.01 | 0.95 | 1113.23 | 0.14 | 126.03 |
| 80 | 123.00 | 0.80 | 0.01 | 1.08 | 1114.75 | 0.17 | 154.80 |
| 90 | 143.00 | 0.90 | 0.01 | 1.22 | 1116.27 | 0.20 | 179.73 |
| 100 | 164.00 | 1.00 | 0.01 | 1.35 | 1117.80 | 0.23 | 205.84 |
| 110 | 186.00 | 1.10 | 0.01 | 1.49 | 1119.33 | 0.26 | 233.13 |
| 120 | 207.00 | 1.20 | 0.02 | 1.62 | 1120.87 | 0.29 | 259.10 |
| 130 | 225.00 | 1.30 | 0.02 | 1.76 | 1122.41 | 0.32 | 281.24 |
| 140 | 249.00 | 1.40 | 0.02 | 1.89 | 1123.96 | 0.35 | 310.81 |
| 150 | 274.00 | 1.50 | 0.02 | 2.03 | 1125.50 | 0.38 | 341.55 |
| 160 | 301.00 | 1.60 | 0.02 | 2.16 | 1127.06 | 0.42 | 374.68 |
| 170 | 329.00 | 1.70 | 0.02 | 2.30 | 1128.62 | 0.46 | 408.97 |
| 180 | 350.00 | 1.80 | 0.02 | 2.43 | 1130.18 | 0.49 | 434.48 |
| 190 | 377.00 | 1.90 | 0.03 | 2.57 | 1131.75 | 0.53 | 467.35 |
| 200 | 405.00 | 2.00 | 0.03 | 2.70 | 1133.32 | 0.57 | 501.36 |
| 210 | 392.00 | 2.10 | 0.03 | 2.84 | 1134.89 | 0.55 | 484.59 |

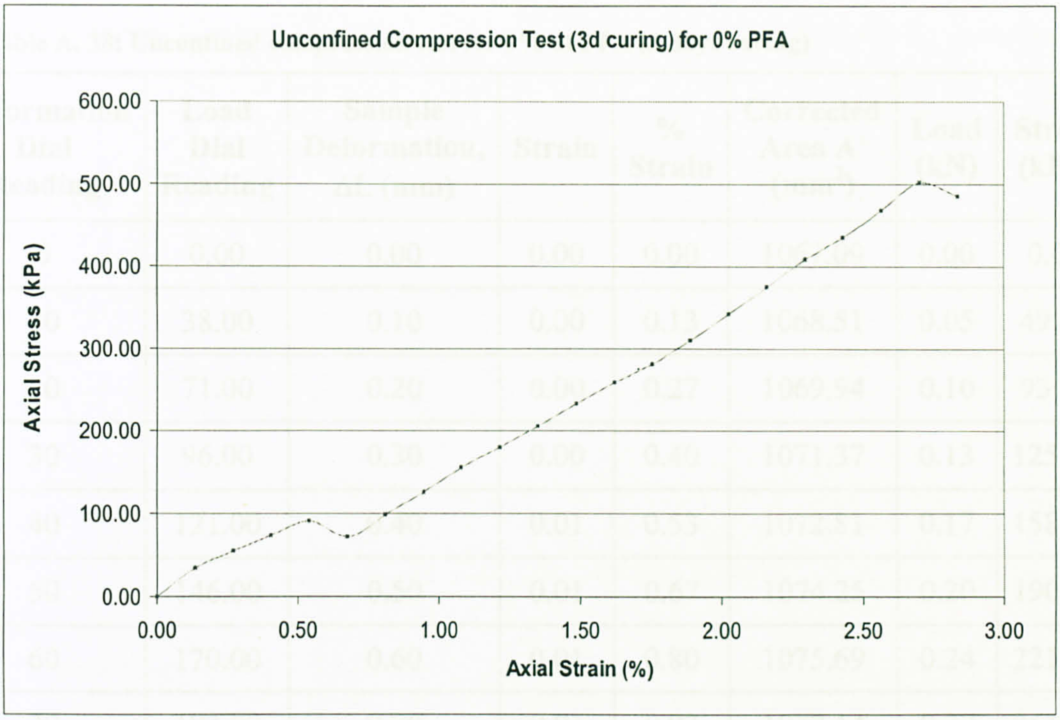



**Figure A. 25: Stress vs. Strain for 0% PFA (3 days curing)**

**Table A. 38: Unconfined compression test for 9% of PFA (3 days curing)**

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1067.09 | 0.00 | 0.00 |
| 10 | 38.00 | 0.10 | 0.00 | 0.13 | 1068.51 | 0.05 | 49.89 |
| 20 | 71.00 | 0.20 | 0.00 | 0.27 | 1069.94 | 0.10 | 93.10 |
| 30 | 96.00 | 0.30 | 0.00 | 0.40 | 1071.37 | 0.13 | 125.71 |
| 40 | 121.00 | 0.40 | 0.01 | 0.53 | 1072.81 | 0.17 | 158.24 |
| 50 | 146.00 | 0.50 | 0.01 | 0.67 | 1074.25 | 0.20 | 190.67 |
| 60 | 170.00 | 0.60 | 0.01 | 0.80 | 1075.69 | 0.24 | 221.72 |
| 70 | 193.00 | 0.70 | 0.01 | 0.93 | 1077.14 | 0.27 | 251.38 |
| 80 | 217.00 | 0.80 | 0.01 | 1.07 | 1078.59 | 0.30 | 282.26 |
| 90 | 240.00 | 0.90 | 0.01 | 1.20 | 1080.05 | 0.34 | 311.76 |
| 100 | 261.00 | 1.00 | 0.01 | 1.33 | 1081.51 | 0.37 | 338.58 |
| 110 | 281.00 | 1.10 | 0.01 | 1.47 | 1082.97 | 0.39 | 364.03 |
| 120 | 300.00 | 1.20 | 0.02 | 1.60 | 1084.44 | 0.42 | 388.12 |
| 130 | 319.00 | 1.30 | 0.02 | 1.73 | 1085.91 | 0.45 | 412.14 |
| 140 | 341.00 | 1.40 | 0.02 | 1.87 | 1087.39 | 0.48 | 439.96 |
| 150 | 366.00 | 1.50 | 0.02 | 2.00 | 1088.87 | 0.51 | 471.58 |
| 160 | 387.00 | 1.60 | 0.02 | 2.13 | 1090.35 | 0.54 | 497.96 |
| 170 | 395.00 | 1.70 | 0.02 | 2.27 | 1091.84 | 0.55 | 507.56 |
| 180 | 407.00 | 1.80 | 0.02 | 2.40 | 1093.33 | 0.57 | 522.26 |
| 190 | 413.00 | 1.90 | 0.03 | 2.53 | 1094.82 | 0.58 | 529.24 |
| 200 | 405.00 | 2.00 | 0.03 | 2.67 | 1096.32 | 0.57 | 518.28 |

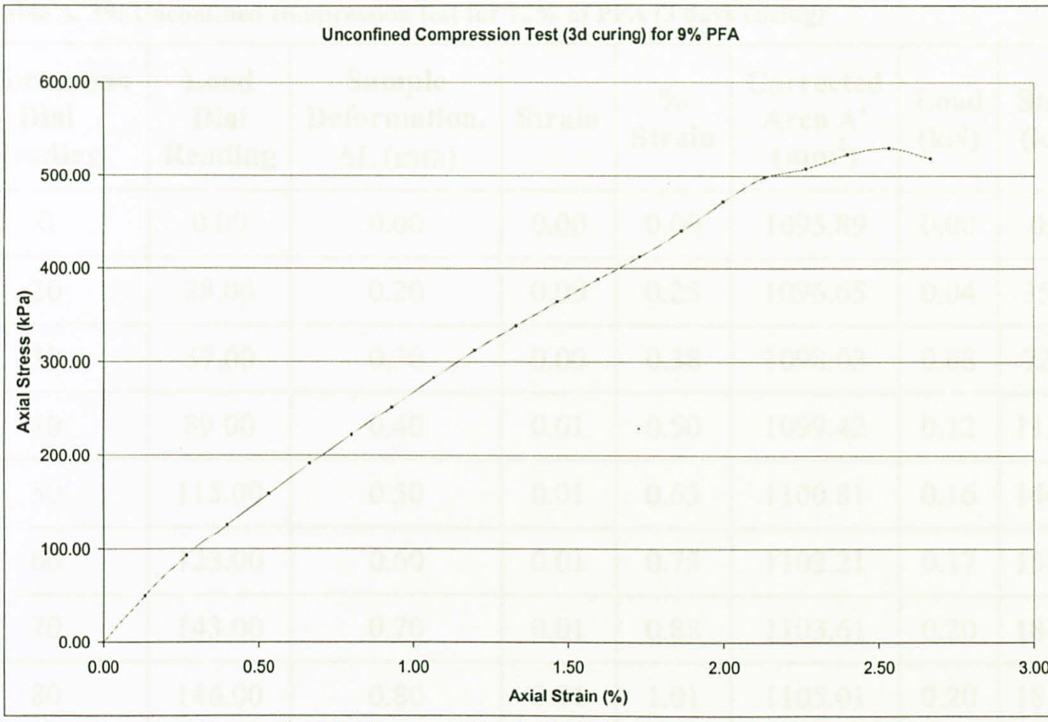



**Figure A. 26: Stress vs. Strain for 9% PFA (3 days curing)**

**Table A. 39: Unconfined compression test for 12% of PFA (3 days curing)**

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1093.89 | 0.00 | 0.00 |
| 20 | 28.00 | 0.20 | 0.00 | 0.25 | 1096.65 | 0.04 | 35.82 |
| 30 | 57.00 | 0.30 | 0.00 | 0.38 | 1098.03 | 0.08 | 72.83 |
| 40 | 89.00 | 0.40 | 0.01 | 0.50 | 1099.42 | 0.12 | 113.57 |
| 50 | 115.00 | 0.50 | 0.01 | 0.63 | 1100.81 | 0.16 | 146.57 |
| 60 | 123.00 | 0.60 | 0.01 | 0.75 | 1102.21 | 0.17 | 156.56 |
| 70 | 143.00 | 0.70 | 0.01 | 0.88 | 1103.61 | 0.20 | 181.79 |
| 80 | 146.00 | 0.80 | 0.01 | 1.01 | 1105.01 | 0.20 | 185.37 |
| 90 | 154.00 | 0.90 | 0.01 | 1.13 | 1106.42 | 0.22 | 195.28 |
| 100 | 165.00 | 1.00 | 0.01 | 1.26 | 1107.83 | 0.23 | 208.96 |
| 110 | 180.00 | 1.10 | 0.01 | 1.38 | 1109.24 | 0.25 | 227.66 |
| 120 | 182.00 | 1.20 | 0.02 | 1.51 | 1110.66 | 0.26 | 229.90 |
| 130 | 194.00 | 1.30 | 0.02 | 1.64 | 1112.08 | 0.27 | 244.74 |
| 140 | 210.00 | 1.40 | 0.02 | 1.76 | 1113.50 | 0.29 | 264.59 |
| 150 | 218.00 | 1.50 | 0.02 | 1.89 | 1114.93 | 0.31 | 274.32 |
| 160 | 249.00 | 1.60 | 0.02 | 2.01 | 1116.36 | 0.35 | 312.93 |
| 170 | 265.00 | 1.70 | 0.02 | 2.14 | 1117.79 | 0.37 | 332.61 |
| 180 | 278.00 | 1.80 | 0.02 | 2.26 | 1119.23 | 0.39 | 348.47 |
| 190 | 295.00 | 1.90 | 0.02 | 2.39 | 1120.68 | 0.41 | 369.31 |
| 200 | 325.00 | 2.00 | 0.03 | 2.52 | 1122.12 | 0.46 | 406.34 |
| 210 | 360.00 | 2.10 | 0.03 | 2.64 | 1123.57 | 0.51 | 449.52 |
| 220 | 390.00 | 2.20 | 0.03 | 2.77 | 1125.03 | 0.55 | 486.35 |
| 230 | 425.00 | 2.30 | 0.03 | 2.89 | 1126.48 | 0.60 | 529.31 |
| 240 | 450.00 | 2.40 | 0.03 | 3.02 | 1127.94 | 0.63 | 559.72 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 250 | 480.00 | 2.50 | 0.03 | 3.15 | 1129.41 | 0.67 | 596.26 |
| 260 | 510.00 | 2.60 | 0.03 | 3.27 | 1130.88 | 0.72 | 632.70 |
| 270 | 539.00 | 2.70 | 0.03 | 3.40 | 1132.35 | 0.76 | 667.81 |
| 280 | 560.00 | 2.80 | 0.04 | 3.52 | 1133.83 | 0.79 | 692.93 |
| 290 | 566.00 | 2.90 | 0.04 | 3.65 | 1135.31 | 0.79 | 699.44 |
| 300 | 570.00 | 3.00 | 0.04 | 3.77 | 1136.79 | 0.80 | 703.46 |
| 310 | 578.00 | 3.10 | 0.04 | 3.90 | 1138.28 | 0.81 | 712.40 |
| 320 | 579.00 | 3.20 | 0.04 | 4.03 | 1139.77 | 0.81 | 712.70 |
| 330 | 550 | 3.30 | 0.04 | 4.15 | 1141.27 | 0.77 | 676.12 |
| 340 | 480 | 3.40 | 0.04 | 4.28 | 1142.77 | 0.67 | 589.29 |

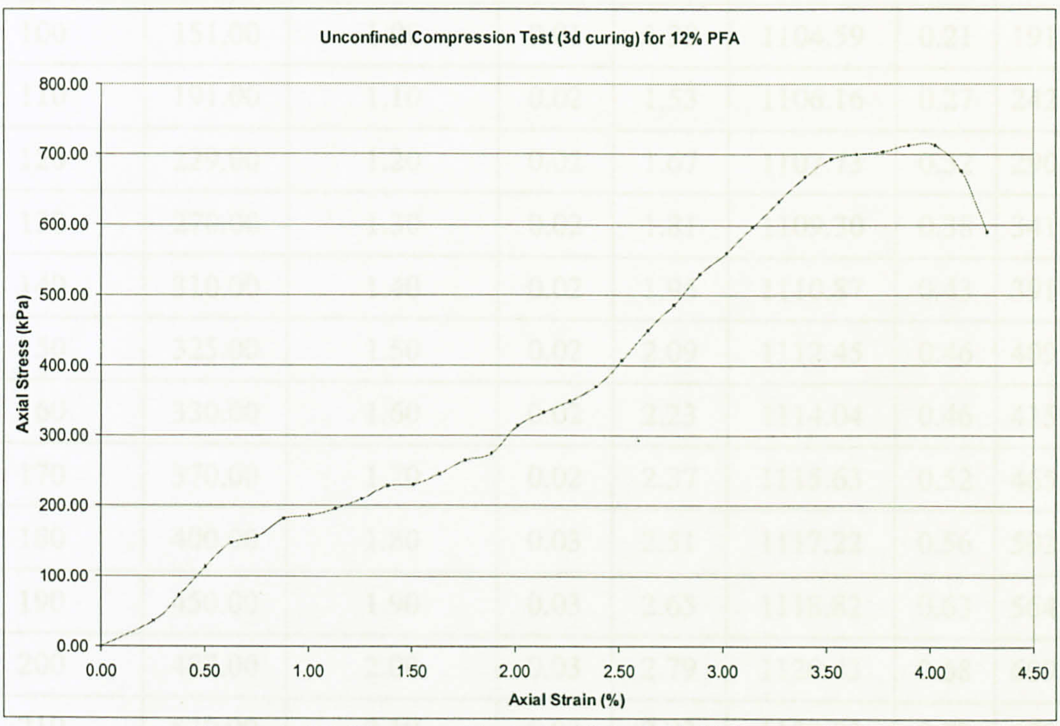



**Figure A. 27: Stress vs. Strain for 12% PFA (3 days curing)**

**Table A. 40: Unconfined compression test for 15% of PFA (3 days curing)**

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1089.20 | 0.00 | 0.00 |
| 20 | 0.00 | 0.20 | 0.00 | 0.28 | 1092.25 | 0.00 | 0.00 |
| 30 | 10.00 | 0.30 | 0.00 | 0.42 | 1093.78 | 0.01 | 12.83 |
| 40 | 21.00 | 0.40 | 0.01 | 0.56 | 1095.31 | 0.03 | 26.90 |
| 50 | 30.00 | 0.50 | 0.01 | 0.70 | 1096.85 | 0.04 | 38.37 |
| 60 | 35.00 | 0.60 | 0.01 | 0.84 | 1098.39 | 0.05 | 44.71 |
| 70 | 54.00 | 0.70 | 0.01 | 0.98 | 1099.93 | 0.08 | 68.88 |
| 80 | 86.00 | 0.80 | 0.01 | 1.11 | 1101.48 | 0.12 | 109.54 |
| 90 | 113.00 | 0.90 | 0.01 | 1.25 | 1103.04 | 0.16 | 143.73 |
| 100 | 151.00 | 1.00 | 0.01 | 1.39 | 1104.59 | 0.21 | 191.79 |
| 110 | 191.00 | 1.10 | 0.02 | 1.53 | 1106.16 | 0.27 | 242.25 |
| 120 | 229.00 | 1.20 | 0.02 | 1.67 | 1107.73 | 0.32 | 290.03 |
| 130 | 270.00 | 1.30 | 0.02 | 1.81 | 1109.30 | 0.38 | 341.48 |
| 140 | 310.00 | 1.40 | 0.02 | 1.95 | 1110.87 | 0.43 | 391.51 |
| 150 | 325.00 | 1.50 | 0.02 | 2.09 | 1112.45 | 0.46 | 409.87 |
| 160 | 330.00 | 1.60 | 0.02 | 2.23 | 1114.04 | 0.46 | 415.58 |
| 170 | 370.00 | 1.70 | 0.02 | 2.37 | 1115.63 | 0.52 | 465.29 |
| 180 | 400.00 | 1.80 | 0.03 | 2.51 | 1117.22 | 0.56 | 502.30 |
| 190 | 450.00 | 1.90 | 0.03 | 2.65 | 1118.82 | 0.63 | 564.28 |
| 200 | 487.00 | 2.00 | 0.03 | 2.79 | 1120.43 | 0.68 | 609.81 |
| 210 | 520.00 | 2.10 | 0.03 | 2.93 | 1122.03 | 0.73 | 650.19 |
| 220 | 557.00 | 2.20 | 0.03 | 3.07 | 1123.65 | 0.78 | 695.46 |
| 230 | 589.00 | 2.30 | 0.03 | 3.20 | 1125.27 | 0.83 | 734.36 |
| 240 | 621.00 | 2.40 | 0.03 | 3.34 | 1126.89 | 0.87 | 773.14 |
| 250 | 625.00 | 2.50 | 0.03 | 3.48 | 1128.51 | 0.88 | 777.00 |
| 260 | 630.00 | 2.60 | 0.04 | 3.62 | 1130.15 | 0.88 | 782.08 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 270 | 656.00 | 2.70 | 0.04 | 3.76 | 1131.78 | 0.92 | 813.18 |
| 280 | 678.00 | 2.80 | 0.04 | 3.90 | 1133.42 | 0.95 | 839.24 |
| 290 | 678.00 | 2.90 | 0.04 | 4.04 | 1135.07 | 0.95 | 838.02 |
| 300 | 685.00 | 3.00 | 0.04 | 4.18 | 1136.72 | 0.96 | 845.44 |
| 310 | 696.00 | 3.10 | 0.04 | 4.32 | 1138.37 | 0.98 | 857.77 |
| 320 | 710.00 | 3.20 | 0.04 | 4.46 | 1140.03 | 1.00 | 873.75 |
| 330 | 739.00 | 3.30 | 0.05 | 4.60 | 1141.70 | 1.04 | 908.11 |
| 340 | 760.00 | 3.40 | 0.05 | 4.74 | 1143.37 | 1.07 | 932.55 |
| 350 | 780.00 | 3.50 | 0.05 | 4.88 | 1145.04 | 1.09 | 955.69 |
| 360 | 800.00 | 3.60 | 0.05 | 5.02 | 1146.72 | 1.12 | 978.76 |
| 370 | 785.00 | 3.70 | 0.05 | 5.16 | 1148.41 | 1.10 | 959.00 |
| 380 | 700.00 | 3.80 | 0.05 | 5.29 | 1150.10 | 0.98 | 853.90 |

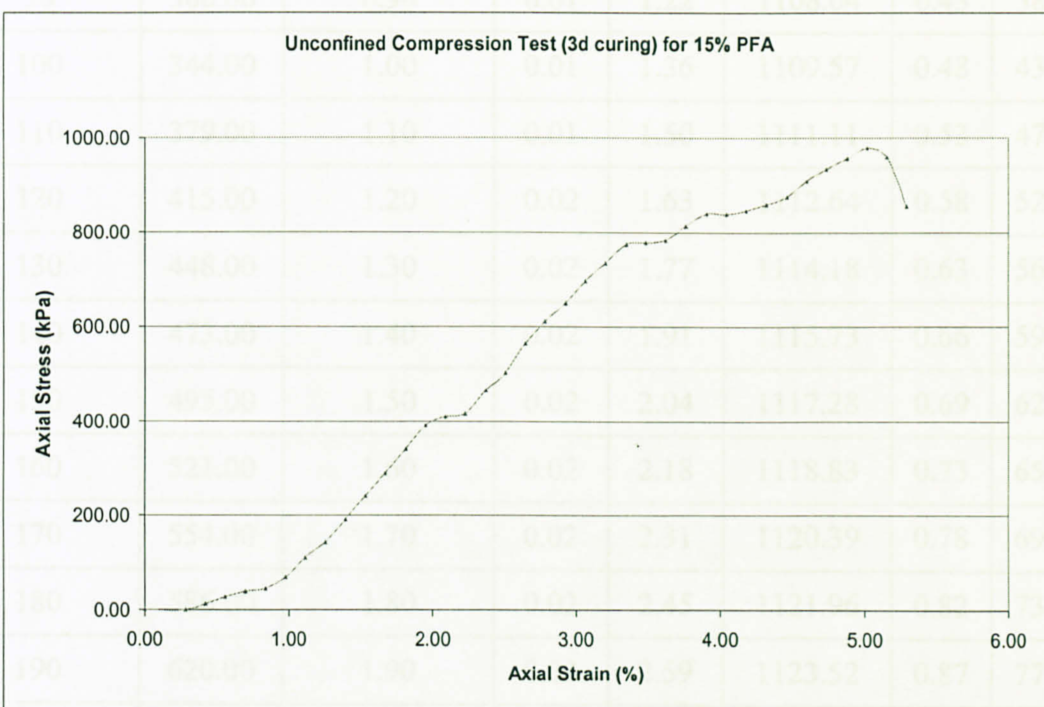



**Figure A. 28: Stress vs. Strain for 15% PFA (3 days curing)**

Table A. 41: Unconfined compression test for 18% of PFA (3 days curing)

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1094.48 | 0.00 | 0.00 |
| 10 | 34.00 | 0.10 | 0.00 | 0.14 | 1095.97 | 0.05 | 43.52 |
| 20 | 61.00 | 0.20 | 0.00 | 0.27 | 1097.46 | 0.09 | 77.98 |
| 30 | 93.00 | 0.30 | 0.00 | 0.41 | 1098.96 | 0.13 | 118.73 |
| 40 | 130.00 | 0.40 | 0.01 | 0.54 | 1100.46 | 0.18 | 165.73 |
| 50 | 165.00 | 0.50 | 0.01 | 0.68 | 1101.97 | 0.23 | 210.07 |
| 60 | 200.00 | 0.60 | 0.01 | 0.82 | 1103.48 | 0.28 | 254.28 |
| 70 | 238.00 | 0.70 | 0.01 | 0.95 | 1105.00 | 0.33 | 302.18 |
| 80 | 273.00 | 0.80 | 0.01 | 1.09 | 1106.52 | 0.38 | 346.14 |
| 90 | 308.00 | 0.90 | 0.01 | 1.22 | 1108.04 | 0.43 | 389.98 |
| 100 | 344.00 | 1.00 | 0.01 | 1.36 | 1109.57 | 0.48 | 434.96 |
| 110 | 379.00 | 1.10 | 0.01 | 1.50 | 1111.11 | 0.53 | 478.55 |
| 120 | 415.00 | 1.20 | 0.02 | 1.63 | 1112.64 | 0.58 | 523.28 |
| 130 | 448.00 | 1.30 | 0.02 | 1.77 | 1114.18 | 0.63 | 564.11 |
| 140 | 473.00 | 1.40 | 0.02 | 1.91 | 1115.73 | 0.66 | 594.77 |
| 150 | 495.00 | 1.50 | 0.02 | 2.04 | 1117.28 | 0.69 | 621.57 |
| 160 | 521.00 | 1.60 | 0.02 | 2.18 | 1118.83 | 0.73 | 653.31 |
| 170 | 554.00 | 1.70 | 0.02 | 2.31 | 1120.39 | 0.78 | 693.72 |
| 180 | 586.00 | 1.80 | 0.02 | 2.45 | 1121.96 | 0.82 | 732.77 |
| 190 | 620.00 | 1.90 | 0.03 | 2.59 | 1123.52 | 0.87 | 774.20 |
| 200 | 649.00 | 2.00 | 0.03 | 2.72 | 1125.09 | 0.91 | 809.29 |
| 210 | 676.00 | 2.10 | 0.03 | 2.86 | 1126.67 | 0.95 | 841.77 |
| 220 | 707.00 | 2.20 | 0.03 | 2.99 | 1128.25 | 0.99 | 879.14 |
| 230 | 735.00 | 2.30 | 0.03 | 3.13 | 1129.84 | 1.03 | 912.68 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 240 | 761.00 | 2.40 | 0.03 | 3.27 | 1131.42 | 1.07 | 943.64 |
| 250 | 791.00 | 2.50 | 0.03 | 3.40 | 1133.02 | 1.11 | 979.46 |
| 260 | 818.00 | 2.60 | 0.04 | 3.54 | 1134.62 | 1.15 | 1011.46 |
| 270 | 845.00 | 2.70 | 0.04 | 3.67 | 1136.22 | 1.19 | 1043.38 |
| 280 | 870.00 | 2.80 | 0.04 | 3.81 | 1137.83 | 1.22 | 1072.73 |
| 290 | 891.00 | 2.90 | 0.04 | 3.95 | 1139.44 | 1.25 | 1097.07 |
| 300 | 909.00 | 3.00 | 0.04 | 4.08 | 1141.06 | 1.28 | 1117.64 |
| 310 | 870.00 | 3.10 | 0.04 | 4.22 | 1142.68 | 1.22 | 1068.17 |

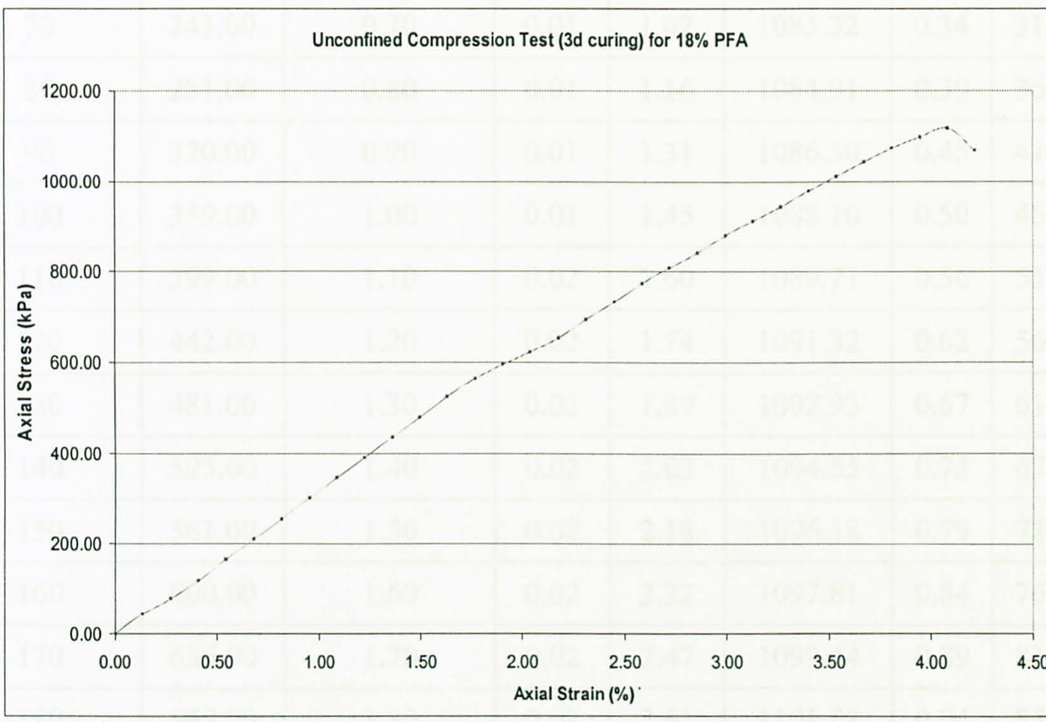



**Figure A. 29: Stress vs. Strain for 18% PFA (3 days curing)**

**Table A. 42: Unconfined compression test for 21% of PFA (3 days curing)**

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1072.31 | 0.00 | 0.00 |
| 10 | 35.00 | 0.10 | 0.00 | 0.15 | 1073.87 | 0.05 | 45.73 |
| 20 | 64.00 | 0.20 | 0.00 | 0.29 | 1075.43 | 0.09 | 83.49 |
| 30 | 97.00 | 0.30 | 0.00 | 0.44 | 1077.00 | 0.14 | 126.36 |
| 40 | 130.00 | 0.40 | 0.01 | 0.58 | 1078.57 | 0.18 | 169.10 |
| 50 | 169.00 | 0.50 | 0.01 | 0.73 | 1080.15 | 0.24 | 219.51 |
| 60 | 203.00 | 0.60 | 0.01 | 0.87 | 1081.73 | 0.28 | 263.28 |
| 70 | 241.00 | 0.70 | 0.01 | 1.02 | 1083.32 | 0.34 | 312.11 |
| 80 | 281.00 | 0.80 | 0.01 | 1.16 | 1084.91 | 0.39 | 363.38 |
| 90 | 320.00 | 0.90 | 0.01 | 1.31 | 1086.50 | 0.45 | 413.20 |
| 100 | 359.00 | 1.00 | 0.01 | 1.45 | 1088.10 | 0.50 | 462.88 |
| 110 | 399.00 | 1.10 | 0.02 | 1.60 | 1089.71 | 0.56 | 513.70 |
| 120 | 442.00 | 1.20 | 0.02 | 1.74 | 1091.32 | 0.62 | 568.22 |
| 130 | 481.00 | 1.30 | 0.02 | 1.89 | 1092.93 | 0.67 | 617.44 |
| 140 | 523.00 | 1.40 | 0.02 | 2.03 | 1094.55 | 0.73 | 670.36 |
| 150 | 561.00 | 1.50 | 0.02 | 2.18 | 1096.18 | 0.79 | 718.01 |
| 160 | 600.00 | 1.60 | 0.02 | 2.32 | 1097.81 | 0.84 | 766.78 |
| 170 | 636.00 | 1.70 | 0.02 | 2.47 | 1099.44 | 0.89 | 811.58 |
| 180 | 668.00 | 1.80 | 0.03 | 2.61 | 1101.08 | 0.94 | 851.15 |
| 190 | 705.00 | 1.90 | 0.03 | 2.76 | 1102.72 | 0.99 | 896.95 |
| 200 | 740.00 | 2.00 | 0.03 | 2.90 | 1104.37 | 1.04 | 940.07 |
| 210 | 762.00 | 2.10 | 0.03 | 3.05 | 1106.03 | 1.07 | 966.57 |
| 220 | 796.00 | 2.20 | 0.03 | 3.19 | 1107.69 | 1.12 | 1008.19 |
| 230 | 828.00 | 2.30 | 0.03 | 3.34 | 1109.35 | 1.16 | 1047.15 |
| 240 | 858.00 | 2.40 | 0.03 | 3.48 | 1111.02 | 1.20 | 1083.46 |
| 250 | 887.00 | 2.50 | 0.04 | 3.63 | 1112.69 | 1.24 | 1118.39 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 260 | 923.00 | 2.60 | 0.04 | 3.77 | 1114.37 | 1.29 | 1162.03 |
| 270 | 952.00 | 2.70 | 0.04 | 3.92 | 1116.05 | 1.34 | 1196.73 |
| 280 | 965.00 | 2.80 | 0.04 | 4.07 | 1117.74 | 1.35 | 1211.24 |
| 290 | 973.00 | 2.90 | 0.04 | 4.21 | 1119.44 | 1.37 | 1219.44 |
| 300 | 977.00 | 3.00 | 0.04 | 4.36 | 1121.14 | 1.37 | 1222.59 |
| 310 | 920.00 | 3.10 | 0.05 | 4.50 | 1122.84 | 1.29 | 1149.52 |

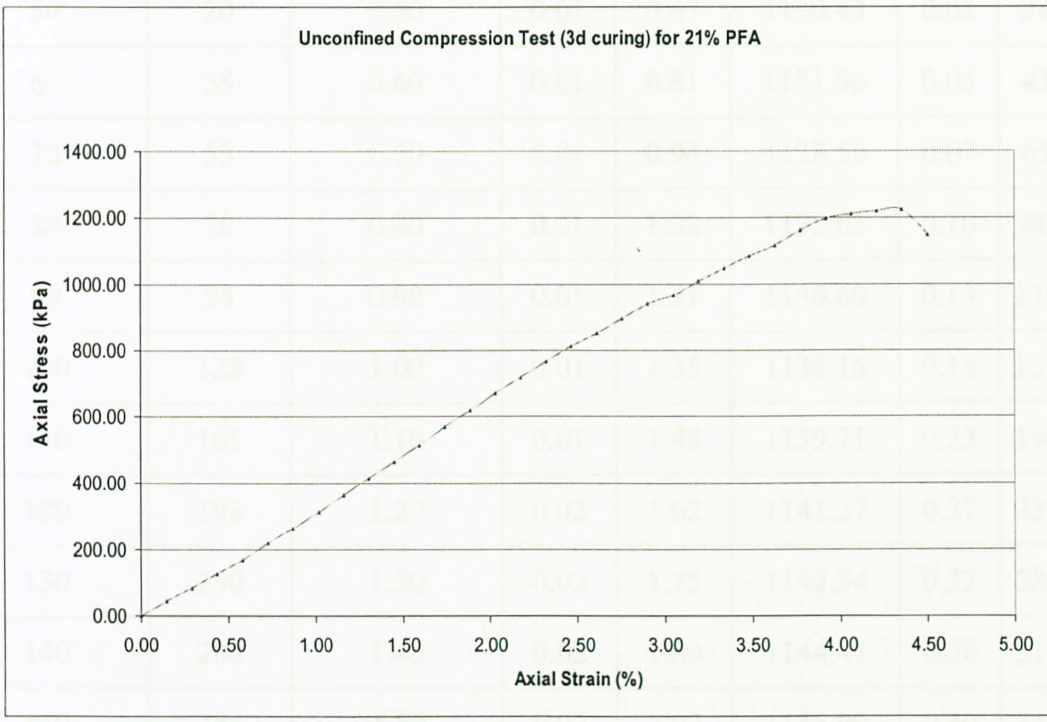



**Figure A. 30: Stress vs. Strain for 21% PFA (3 days curing)**

Table A. 43: Unconfined compression test for 24% of PFA (3 days curing)

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0.00 | 0.00 | 0.00 | 1122.80 | 0.00 | 0.00 |
| 20 | 0 | 0.20 | 0.00 | 0.27 | 1125.84 | 0.00 | 0.00 |
| 40 | 5 | 0.40 | 0.01 | 0.54 | 1128.89 | 0.01 | 6.21 |
| 50 | 20 | 0.50 | 0.01 | 0.67 | 1130.43 | 0.03 | 24.82 |
| 60 | 35 | 0.60 | 0.01 | 0.81 | 1131.96 | 0.05 | 43.38 |
| 70 | 53 | 0.70 | 0.01 | 0.94 | 1133.50 | 0.07 | 65.60 |
| 80 | 70 | 0.80 | 0.01 | 1.08 | 1135.05 | 0.10 | 86.52 |
| 90 | 94 | 0.90 | 0.01 | 1.21 | 1136.60 | 0.13 | 116.03 |
| 100 | 128 | 1.00 | 0.01 | 1.35 | 1138.15 | 0.18 | 157.78 |
| 110 | 161 | 1.10 | 0.01 | 1.48 | 1139.71 | 0.23 | 198.19 |
| 120 | 193 | 1.20 | 0.02 | 1.62 | 1141.27 | 0.27 | 237.25 |
| 130 | 230 | 1.30 | 0.02 | 1.75 | 1142.84 | 0.32 | 282.35 |
| 140 | 260 | 1.40 | 0.02 | 1.89 | 1144.41 | 0.36 | 318.74 |
| 150 | 285 | 1.50 | 0.02 | 2.02 | 1145.99 | 0.40 | 348.91 |
| 160 | 313 | 1.60 | 0.02 | 2.16 | 1147.57 | 0.44 | 382.66 |
| 170 | 342 | 1.70 | 0.02 | 2.29 | 1149.15 | 0.48 | 417.54 |
| 180 | 360 | 1.80 | 0.02 | 2.43 | 1150.74 | 0.51 | 438.91 |
| 190 | 382 | 1.90 | 0.03 | 2.56 | 1152.33 | 0.54 | 465.08 |
| 200 | 418 | 2.00 | 0.03 | 2.70 | 1153.93 | 0.59 | 508.21 |
| 210 | 454 | 2.10 | 0.03 | 2.83 | 1155.53 | 0.64 | 551.21 |
| 220 | 490 | 2.20 | 0.03 | 2.97 | 1157.14 | 0.69 | 594.10 |
| 230 | 521 | 2.30 | 0.03 | 3.10 | 1158.75 | 0.73 | 630.80 |
| 240 | 556 | 2.40 | 0.03 | 3.24 | 1160.36 | 0.78 | 672.24 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 250 | 587 | 2.50 | 0.03 | 3.37 | 1161.98 | 0.82 | 708.73 |
| 260 | 627 | 2.60 | 0.04 | 3.51 | 1163.61 | 0.88 | 755.97 |
| 270 | 653 | 2.70 | 0.04 | 3.64 | 1165.24 | 0.92 | 786.22 |
| 280 | 684 | 2.80 | 0.04 | 3.78 | 1166.87 | 0.96 | 822.39 |
| 290 | 706 | 2.90 | 0.04 | 3.91 | 1168.51 | 0.99 | 847.65 |
| 300 | 720 | 3.00 | 0.04 | 4.05 | 1170.15 | 1.01 | 863.25 |
| 310 | 746 | 3.10 | 0.04 | 4.18 | 1171.80 | 1.05 | 893.17 |
| 320 | 770 | 3.20 | 0.04 | 4.32 | 1173.45 | 1.08 | 920.60 |
| 330 | 792 | 3.30 | 0.04 | 4.45 | 1175.11 | 1.11 | 945.57 |
| 340 | 700 | 3.40 | 0.05 | 4.59 | 1176.77 | 0.98 | 834.55 |

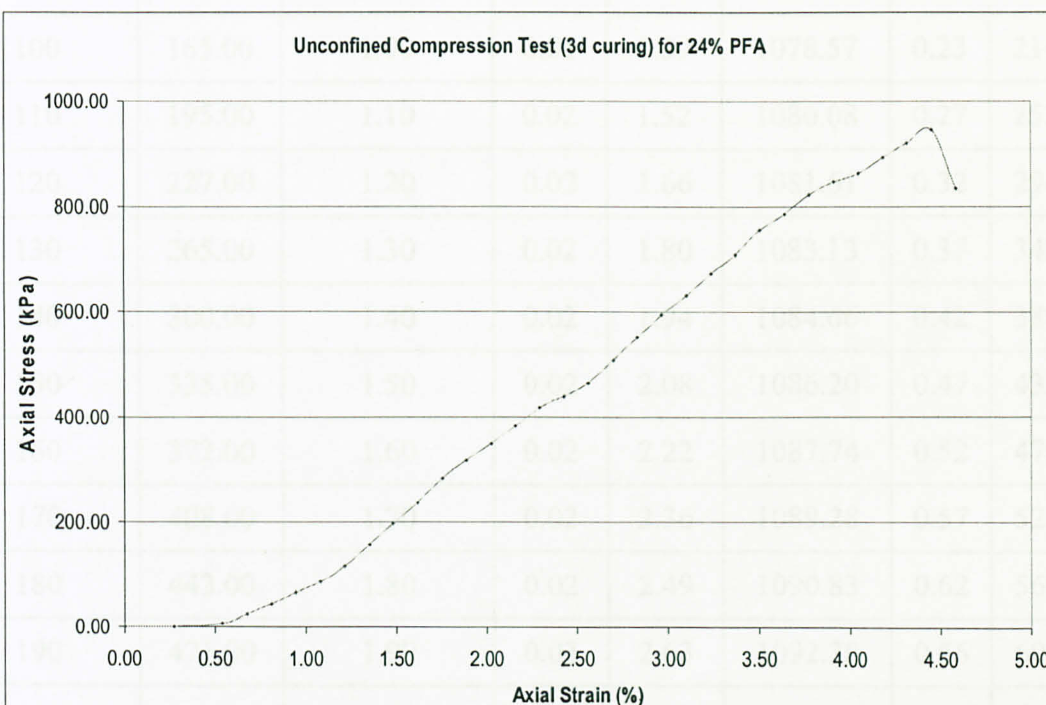



**Figure A. 31: Stress vs. Strain for 24% PFA (3 days curing)**

Table A. 44: Unconfined compression test for 0% of PFA (7 days curing)

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1063.62 | 0.00 | 0.00 |
| 10 | 30.00 | 0.10 | 0.00 | 0.14 | 1065.09 | 0.04 | 39.52 |
| 20 | 43.00 | 0.20 | 0.00 | 0.28 | 1066.57 | 0.06 | 56.56 |
| 30 | 53.00 | 0.30 | 0.00 | 0.42 | 1068.06 | 0.07 | 69.62 |
| 40 | 59.00 | 0.40 | 0.01 | 0.55 | 1069.55 | 0.08 | 77.39 |
| 50 | 76.00 | 0.50 | 0.01 | 0.69 | 1071.04 | 0.11 | 99.55 |
| 60 | 90.00 | 0.60 | 0.01 | 0.83 | 1072.54 | 0.13 | 117.73 |
| 70 | 110.00 | 0.70 | 0.01 | 0.97 | 1074.04 | 0.15 | 143.69 |
| 80 | 126.00 | 0.80 | 0.01 | 1.11 | 1075.54 | 0.18 | 164.36 |
| 90 | 143.00 | 0.90 | 0.01 | 1.25 | 1077.05 | 0.20 | 186.27 |
| 100 | 165.00 | 1.00 | 0.01 | 1.39 | 1078.57 | 0.23 | 214.63 |
| 110 | 195.00 | 1.10 | 0.02 | 1.52 | 1080.08 | 0.27 | 253.29 |
| 120 | 227.00 | 1.20 | 0.02 | 1.66 | 1081.61 | 0.32 | 294.44 |
| 130 | 265.00 | 1.30 | 0.02 | 1.80 | 1083.13 | 0.37 | 343.25 |
| 140 | 300.00 | 1.40 | 0.02 | 1.94 | 1084.66 | 0.42 | 388.04 |
| 150 | 335.00 | 1.50 | 0.02 | 2.08 | 1086.20 | 0.47 | 432.69 |
| 160 | 372.00 | 1.60 | 0.02 | 2.22 | 1087.74 | 0.52 | 479.80 |
| 170 | 408.00 | 1.70 | 0.02 | 2.36 | 1089.28 | 0.57 | 525.49 |
| 180 | 443.00 | 1.80 | 0.02 | 2.49 | 1090.83 | 0.62 | 569.76 |
| 190 | 471.00 | 1.90 | 0.03 | 2.63 | 1092.38 | 0.66 | 604.91 |
| 200 | 507.00 | 2.00 | 0.03 | 2.77 | 1093.94 | 0.71 | 650.22 |
| 210 | 536.00 | 2.10 | 0.03 | 2.91 | 1095.50 | 0.75 | 686.43 |
| 220 | 572.00 | 2.20 | 0.03 | 3.05 | 1097.07 | 0.80 | 731.49 |
| 230 | 605.00 | 2.30 | 0.03 | 3.19 | 1098.64 | 0.85 | 772.58 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 240 | 631.00 | 2.40 | 0.03 | 3.33 | 1100.22 | 0.89 | 804.63 |
| 250 | 652.00 | 2.50 | 0.03 | 3.47 | 1101.79 | 0.91 | 830.22 |
| 260 | 676.00 | 2.60 | 0.04 | 3.60 | 1103.38 | 0.95 | 859.54 |
| 270 | 704.00 | 2.70 | 0.04 | 3.74 | 1104.97 | 0.99 | 893.86 |
| 280 | 736.00 | 2.80 | 0.04 | 3.88 | 1106.56 | 1.03 | 933.14 |
| 290 | 770.00 | 2.90 | 0.04 | 4.02 | 1108.16 | 1.08 | 974.84 |
| 300 | 800.00 | 3.00 | 0.04 | 4.16 | 1109.76 | 1.12 | 1011.36 |
| 310 | 832.00 | 3.10 | 0.04 | 4.30 | 1111.37 | 1.17 | 1050.29 |
| 320 | 845.00 | 3.20 | 0.04 | 4.44 | 1112.98 | 1.19 | 1065.16 |
| 330 | 855.00 | 3.30 | 0.05 | 4.57 | 1114.60 | 1.20 | 1076.20 |
| 340 | 859.00 | 3.40 | 0.05 | 4.71 | 1116.22 | 1.21 | 1079.67 |
| 350 | 862.00 | 3.50 | 0.05 | 4.85 | 1117.84 | 1.21 | 1081.86 |
| 360 | 850.00 | 3.60 | 0.05 | 4.99 | 1119.47 | 1.19 | 1065.25 |

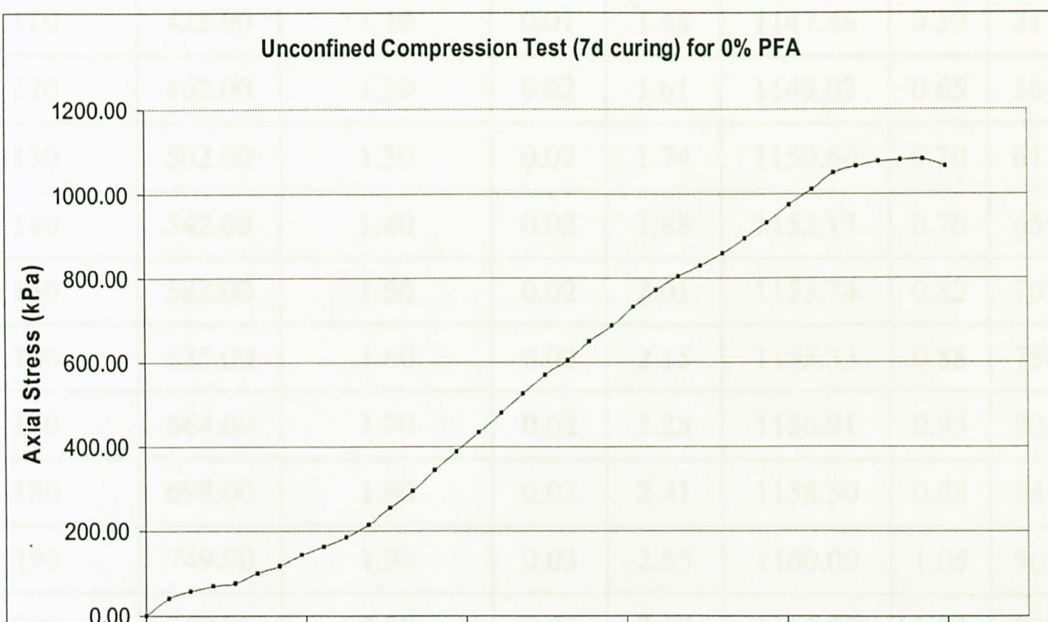



Figure A. 32: Stress vs. Strain for 0% PFA (7 days curing)

Table A. 45: Unconfined compression test for 9% of PFA (7 days curing)

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1130.54 | 0.00 | 0.00 |
| 10 | 42.00 | 0.10 | 0.00 | 0.13 | 1132.05 | 0.06 | 52.05 |
| 20 | 76.00 | 0.20 | 0.00 | 0.27 | 1133.58 | 0.11 | 94.06 |
| 30 | 108.00 | 0.30 | 0.00 | 0.40 | 1135.10 | 0.15 | 133.49 |
| 40 | 141.00 | 0.40 | 0.01 | 0.54 | 1136.63 | 0.20 | 174.04 |
| 50 | 180.00 | 0.50 | 0.01 | 0.67 | 1138.17 | 0.25 | 221.88 |
| 60 | 216.00 | 0.60 | 0.01 | 0.80 | 1139.71 | 0.30 | 265.89 |
| 70 | 257.00 | 0.70 | 0.01 | 0.94 | 1141.25 | 0.36 | 315.94 |
| 80 | 298.00 | 0.80 | 0.01 | 1.07 | 1142.80 | 0.42 | 365.84 |
| 90 | 340.00 | 0.90 | 0.01 | 1.21 | 1144.35 | 0.48 | 416.84 |
| 100 | 380.00 | 1.00 | 0.01 | 1.34 | 1145.90 | 0.53 | 465.24 |
| 110 | 423.00 | 1.10 | 0.01 | 1.48 | 1147.46 | 0.59 | 517.19 |
| 120 | 462.00 | 1.20 | 0.02 | 1.61 | 1149.03 | 0.65 | 564.10 |
| 130 | 502.00 | 1.30 | 0.02 | 1.74 | 1150.60 | 0.70 | 612.11 |
| 140 | 542.00 | 1.40 | 0.02 | 1.88 | 1152.17 | 0.76 | 659.98 |
| 150 | 582.00 | 1.50 | 0.02 | 2.01 | 1153.74 | 0.82 | 707.72 |
| 160 | 625.00 | 1.60 | 0.02 | 2.15 | 1155.33 | 0.88 | 758.96 |
| 170 | 664.00 | 1.70 | 0.02 | 2.28 | 1156.91 | 0.93 | 805.22 |
| 180 | 698.00 | 1.80 | 0.02 | 2.41 | 1158.50 | 0.98 | 845.29 |
| 190 | 749.00 | 1.90 | 0.03 | 2.55 | 1160.09 | 1.05 | 905.80 |
| 200 | 750.00 | 2.00 | 0.03 | 2.68 | 1161.69 | 1.05 | 905.77 |
| 210 | 770.00 | 2.10 | 0.03 | 2.82 | 1163.30 | 1.08 | 928.64 |
| 220 | 798.00 | 2.20 | 0.03 | 2.95 | 1164.90 | 1.12 | 961.08 |
| 230 | 830.00 | 2.30 | 0.03 | 3.08 | 1166.52 | 1.16 | 998.24 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 240 | 860.00 | 2.40 | 0.03 | 3.22 | 1168.13 | 1.21 | 1032.89 |
| 250 | 890.00 | 2.50 | 0.03 | 3.35 | 1169.75 | 1.25 | 1067.44 |
| 260 | 920.00 | 2.60 | 0.03 | 3.49 | 1171.38 | 1.29 | 1101.89 |
| 270 | 945.00 | 2.70 | 0.04 | 3.62 | 1173.01 | 1.33 | 1130.26 |
| 280 | 947.00 | 2.80 | 0.04 | 3.75 | 1174.64 | 1.33 | 1131.07 |
| 290 | 940.00 | 2.90 | 0.04 | 3.89 | 1176.28 | 1.32 | 1121.15 |

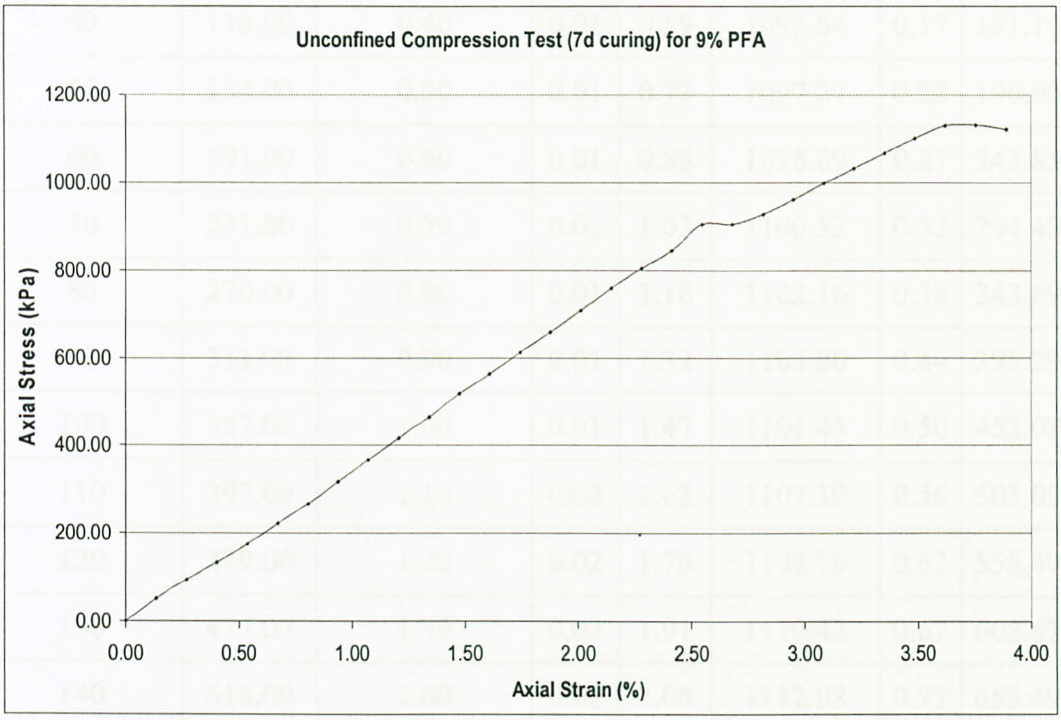



**Figure A. 33: Stress vs. Strain for 9% PFA (7 days curing)**

**Table A. 46: Unconfined compression test for 12% of PFA (7 days curing)**

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1089.20 | 0.00 | 0.00 |
| 10 | 25.00 | 0.10 | 0.00 | 0.15 | 1090.81 | 0.04 | 32.15 |
| 20 | 49.00 | 0.20 | 0.00 | 0.29 | 1092.41 | 0.07 | 62.93 |
| 30 | 85.00 | 0.30 | 0.00 | 0.44 | 1094.03 | 0.12 | 109.00 |
| 40 | 118.00 | 0.40 | 0.01 | 0.59 | 1095.64 | 0.17 | 151.10 |
| 50 | 154.00 | 0.50 | 0.01 | 0.73 | 1097.27 | 0.22 | 196.90 |
| 60 | 191.00 | 0.60 | 0.01 | 0.88 | 1098.89 | 0.27 | 243.85 |
| 70 | 231.00 | 0.70 | 0.01 | 1.03 | 1100.52 | 0.32 | 294.48 |
| 80 | 270.00 | 0.80 | 0.01 | 1.18 | 1102.16 | 0.38 | 343.69 |
| 90 | 311.00 | 0.90 | 0.01 | 1.32 | 1103.80 | 0.44 | 395.29 |
| 100 | 357.00 | 1.00 | 0.01 | 1.47 | 1105.45 | 0.50 | 453.08 |
| 110 | 397.00 | 1.10 | 0.02 | 1.62 | 1107.10 | 0.56 | 503.09 |
| 120 | 439.00 | 1.20 | 0.02 | 1.76 | 1108.76 | 0.62 | 555.49 |
| 130 | 477.00 | 1.30 | 0.02 | 1.91 | 1110.42 | 0.67 | 602.67 |
| 140 | 518.00 | 1.40 | 0.02 | 2.06 | 1112.08 | 0.73 | 653.49 |
| 150 | 556.00 | 1.50 | 0.02 | 2.20 | 1113.75 | 0.78 | 700.38 |
| 160 | 598.00 | 1.60 | 0.02 | 2.35 | 1115.43 | 0.84 | 752.15 |
| 170 | 636.00 | 1.70 | 0.02 | 2.50 | 1117.11 | 0.89 | 798.74 |
| 180 | 674.00 | 1.80 | 0.03 | 2.65 | 1118.80 | 0.95 | 845.19 |
| 190 | 707.00 | 1.90 | 0.03 | 2.79 | 1120.49 | 0.99 | 885.23 |
| 200 | 726.00 | 2.00 | 0.03 | 2.94 | 1122.19 | 1.02 | 907.65 |
| 210 | 732.00 | 2.10 | 0.03 | 3.09 | 1123.89 | 1.03 | 913.77 |
| 220 | 750.00 | 2.20 | 0.03 | 3.23 | 1125.59 | 1.05 | 934.82 |
| 230 | 762.00 | 2.30 | 0.03 | 3.38 | 1127.31 | 1.07 | 948.33 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 240 | 770.00 | 2.40 | 0.04 | 3.53 | 1129.02 | 1.08 | 956.83 |
| 250 | 787.00 | 2.50 | 0.04 | 3.67 | 1130.74 | 1.10 | 976.46 |
| 260 | 796.00 | 2.60 | 0.04 | 3.82 | 1132.47 | 1.12 | 986.12 |
| 270 | 816.00 | 2.70 | 0.04 | 3.97 | 1134.21 | 1.14 | 1009.36 |
| 280 | 830.00 | 2.80 | 0.04 | 4.11 | 1135.94 | 1.16 | 1025.10 |
| 290 | 841.00 | 2.90 | 0.04 | 4.26 | 1137.69 | 1.18 | 1037.10 |
| 300 | 863.00 | 3.00 | 0.04 | 4.41 | 1139.44 | 1.21 | 1062.59 |
| 310 | 882.00 | 3.10 | 0.05 | 4.56 | 1141.19 | 1.24 | 1084.32 |
| 320 | 907.00 | 3.20 | 0.05 | 4.70 | 1142.95 | 1.27 | 1113.34 |
| 330 | 921.00 | 3.30 | 0.05 | 4.85 | 1144.72 | 1.29 | 1128.78 |
| 340 | 933.00 | 3.40 | 0.05 | 5.00 | 1146.49 | 1.31 | 1141.72 |
| 350 | 900.00 | 3.50 | 0.05 | 5.14 | 1148.26 | 1.26 | 1099.63 |

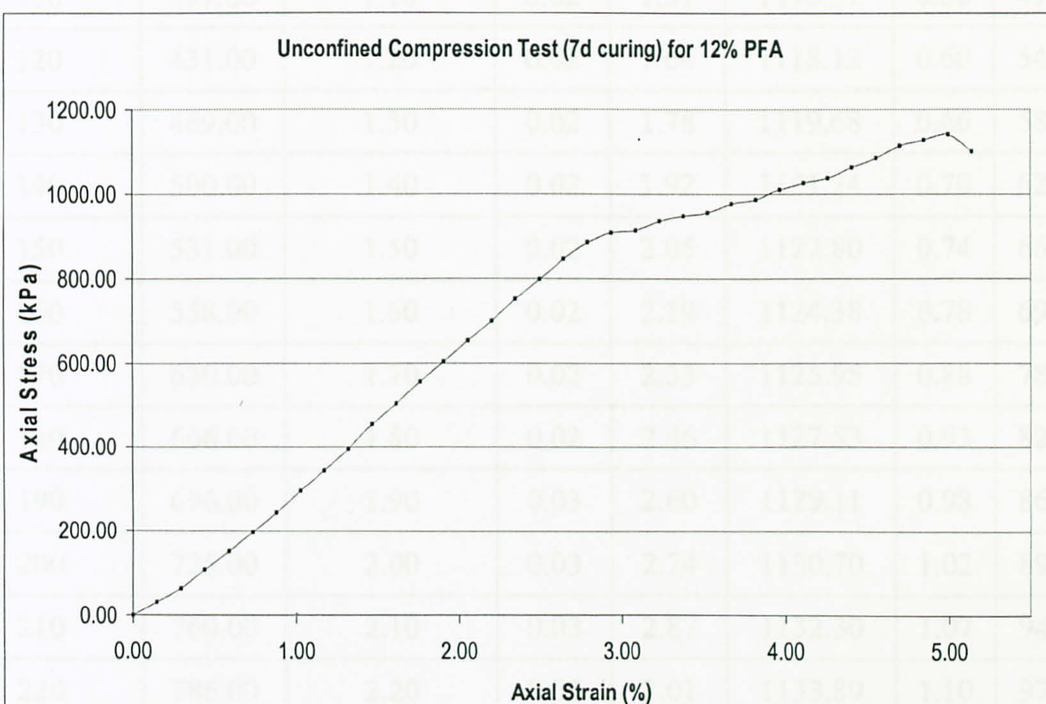



**Figure A. 34: Stress vs. Strain for 12% PFA (7 days curing)**

Table A. 47: Unconfined compression test for 15% of PFA (7 days curing)

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1099.76 | 0.00 | 0.00 |
| 10 | 80.00 | 0.10 | 0.00 | 0.14 | 1101.27 | 0.11 | 101.92 |
| 20 | 110.00 | 0.20 | 0.00 | 0.27 | 1102.78 | 0.15 | 139.94 |
| 30 | 136.00 | 0.30 | 0.00 | 0.41 | 1104.29 | 0.19 | 172.78 |
| 40 | 163.00 | 0.40 | 0.01 | 0.55 | 1105.81 | 0.23 | 206.80 |
| 50 | 194.00 | 0.50 | 0.01 | 0.68 | 1107.33 | 0.27 | 245.79 |
| 60 | 223.00 | 0.60 | 0.01 | 0.82 | 1108.86 | 0.31 | 282.15 |
| 70 | 255.00 | 0.70 | 0.01 | 0.96 | 1110.39 | 0.36 | 322.19 |
| 80 | 289.00 | 0.80 | 0.01 | 1.09 | 1111.93 | 0.41 | 364.64 |
| 90 | 325.00 | 0.90 | 0.01 | 1.23 | 1113.47 | 0.46 | 409.50 |
| 100 | 361.00 | 1.00 | 0.01 | 1.37 | 1115.02 | 0.51 | 454.23 |
| 110 | 397.00 | 1.10 | 0.02 | 1.51 | 1116.57 | 0.56 | 498.83 |
| 120 | 431.00 | 1.20 | 0.02 | 1.64 | 1118.12 | 0.60 | 540.80 |
| 130 | 469.00 | 1.30 | 0.02 | 1.78 | 1119.68 | 0.66 | 587.66 |
| 140 | 500.00 | 1.40 | 0.02 | 1.92 | 1121.24 | 0.70 | 625.63 |
| 150 | 531.00 | 1.50 | 0.02 | 2.05 | 1122.80 | 0.74 | 663.49 |
| 160 | 558.00 | 1.60 | 0.02 | 2.19 | 1124.38 | 0.78 | 696.26 |
| 170 | 630.00 | 1.70 | 0.02 | 2.33 | 1125.95 | 0.88 | 785.00 |
| 180 | 666.00 | 1.80 | 0.02 | 2.46 | 1127.53 | 0.93 | 828.69 |
| 190 | 696.00 | 1.90 | 0.03 | 2.60 | 1129.11 | 0.98 | 864.80 |
| 200 | 725.00 | 2.00 | 0.03 | 2.74 | 1130.70 | 1.02 | 899.57 |
| 210 | 760.00 | 2.10 | 0.03 | 2.87 | 1132.30 | 1.07 | 941.67 |
| 220 | 786.00 | 2.20 | 0.03 | 3.01 | 1133.89 | 1.10 | 972.51 |
| 230 | 819.00 | 2.30 | 0.03 | 3.15 | 1135.50 | 1.15 | 1011.92 |
| 240 | 842.00 | 2.40 | 0.03 | 3.28 | 1137.10 | 1.18 | 1038.86 |
| 250 | 871.00 | 2.50 | 0.03 | 3.42 | 1138.71 | 1.22 | 1073.12 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 260 | 902.00 | 2.60 | 0.04 | 3.56 | 1140.33 | 1.27 | 1109.74 |
| 270 | 930.00 | 2.70 | 0.04 | 3.69 | 1141.95 | 1.30 | 1142.57 |
| 280 | 900.00 | 2.80 | 0.04 | 3.83 | 1143.57 | 1.26 | 1104.14 |

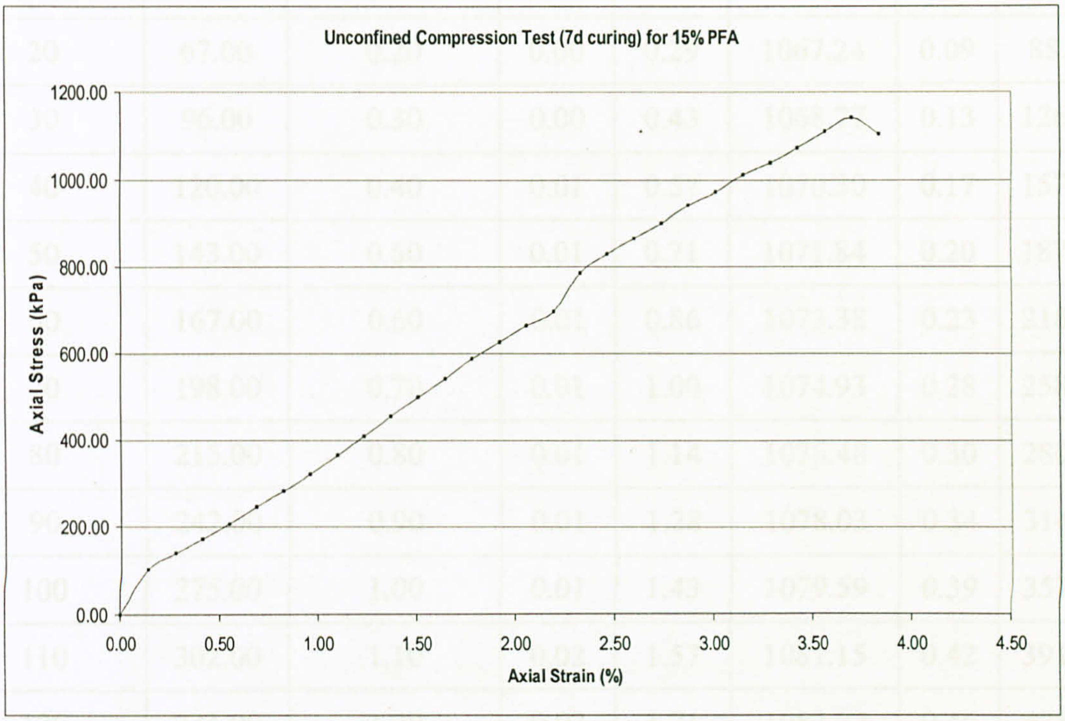



**Figure A. 35: Stress vs. Strain for 15% PFA (7 days curing)**

**Table A. 48: Unconfined compression test for 18% of PFA (7 days curing)**

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1064.20 | 0.00 | 0.00 |
| 10 | 43.00 | 0.10 | 0.00 | 0.14 | 1065.72 | 0.06 | 56.61 |
| 20 | 67.00 | 0.20 | 0.00 | 0.29 | 1067.24 | 0.09 | 88.08 |
| 30 | 96.00 | 0.30 | 0.00 | 0.43 | 1068.77 | 0.13 | 126.02 |
| 40 | 120.00 | 0.40 | 0.01 | 0.57 | 1070.30 | 0.17 | 157.30 |
| 50 | 143.00 | 0.50 | 0.01 | 0.71 | 1071.84 | 0.20 | 187.18 |
| 60 | 167.00 | 0.60 | 0.01 | 0.86 | 1073.38 | 0.23 | 218.28 |
| 70 | 198.00 | 0.70 | 0.01 | 1.00 | 1074.93 | 0.28 | 258.42 |
| 80 | 215.00 | 0.80 | 0.01 | 1.14 | 1076.48 | 0.30 | 280.21 |
| 90 | 242.00 | 0.90 | 0.01 | 1.28 | 1078.03 | 0.34 | 314.94 |
| 100 | 275.00 | 1.00 | 0.01 | 1.43 | 1079.59 | 0.39 | 357.37 |
| 110 | 302.00 | 1.10 | 0.02 | 1.57 | 1081.15 | 0.42 | 391.89 |
| 120 | 331.00 | 1.20 | 0.02 | 1.71 | 1082.72 | 0.46 | 428.90 |
| 130 | 361.00 | 1.30 | 0.02 | 1.85 | 1084.30 | 0.51 | 467.10 |
| 140 | 392.00 | 1.40 | 0.02 | 2.00 | 1085.87 | 0.55 | 506.47 |
| 150 | 422.00 | 1.50 | 0.02 | 2.14 | 1087.46 | 0.59 | 544.44 |
| 160 | 455.00 | 1.60 | 0.02 | 2.28 | 1089.04 | 0.64 | 586.16 |
| 170 | 495.00 | 1.70 | 0.02 | 2.42 | 1090.63 | 0.69 | 636.76 |
| 180 | 538.00 | 1.80 | 0.03 | 2.57 | 1092.23 | 0.75 | 691.06 |
| 190 | 575.00 | 1.90 | 0.03 | 2.71 | 1093.83 | 0.81 | 737.50 |
| 200 | 610.00 | 2.00 | 0.03 | 2.85 | 1095.44 | 0.86 | 781.25 |
| 210 | 645.00 | 2.10 | 0.03 | 2.99 | 1097.05 | 0.90 | 824.86 |
| 220 | 676.00 | 2.20 | 0.03 | 3.14 | 1098.66 | 0.95 | 863.23 |
| 230 | 710.00 | 2.30 | 0.03 | 3.28 | 1100.28 | 1.00 | 905.32 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 240 | 740.00 | 2.40 | 0.03 | 3.42 | 1101.91 | 1.04 | 942.18 |
| 250 | 767.00 | 2.50 | 0.04 | 3.56 | 1103.53 | 1.08 | 975.11 |
| 260 | 795.00 | 2.60 | 0.04 | 3.71 | 1105.17 | 1.12 | 1009.22 |
| 270 | 819.00 | 2.70 | 0.04 | 3.85 | 1106.81 | 1.15 | 1038.14 |
| 280 | 846.00 | 2.80 | 0.04 | 3.99 | 1108.45 | 1.19 | 1070.78 |
| 290 | 869.00 | 2.90 | 0.04 | 4.14 | 1110.10 | 1.22 | 1098.26 |
| 300 | 891 | 3.00 | 0.04 | 4.28 | 1111.75 | 1.25 | 1124.38 |
| 310 | 914 | 3.10 | 0.04 | 4.42 | 1113.41 | 1.28 | 1151.69 |
| 320 | 935 | 3.20 | 0.05 | 4.56 | 1115.08 | 1.31 | 1176.39 |
| 330 | 960 | 3.30 | 0.05 | 4.71 | 1116.74 | 1.35 | 1206.04 |
| 340 | 969 | 3.40 | 0.05 | 4.85 | 1118.42 | 1.36 | 1215.53 |
| 350 | 958 | 3.50 | 0.05 | 4.99 | 1120.10 | 1.34 | 1199.93 |

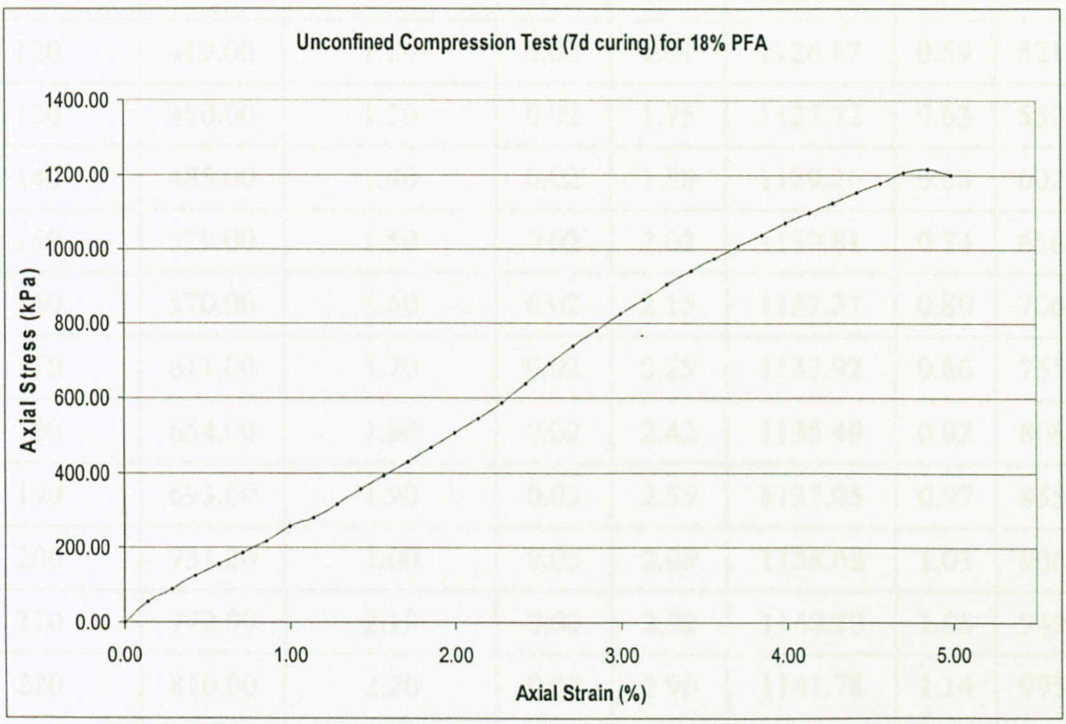



**Figure A. 36: Stress vs. Strain for 18% PFA (7 days curing)**

**Table A. 49: Unconfined compression test for 21% of PFA (7 days curing)**

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1108.00 | 0.00 | 0.00 |
| 10 | 37.00 | 0.10 | 0.00 | 0.13 | 1109.50 | 0.05 | 46.79 |
| 20 | 65.00 | 0.20 | 0.00 | 0.27 | 1110.99 | 0.09 | 82.08 |
| 30 | 115.00 | 0.30 | 0.00 | 0.40 | 1112.49 | 0.16 | 145.03 |
| 40 | 119.00 | 0.40 | 0.01 | 0.54 | 1113.99 | 0.17 | 149.87 |
| 50 | 149.00 | 0.50 | 0.01 | 0.67 | 1115.50 | 0.21 | 187.40 |
| 60 | 180.00 | 0.60 | 0.01 | 0.81 | 1117.02 | 0.25 | 226.08 |
| 70 | 215.00 | 0.70 | 0.01 | 0.94 | 1118.53 | 0.30 | 269.67 |
| 80 | 253.00 | 0.80 | 0.01 | 1.08 | 1120.05 | 0.35 | 316.90 |
| 90 | 290.00 | 0.90 | 0.01 | 1.21 | 1121.58 | 0.41 | 362.76 |
| 100 | 330.00 | 1.00 | 0.01 | 1.34 | 1123.10 | 0.46 | 412.23 |
| 110 | 370.00 | 1.10 | 0.01 | 1.48 | 1124.64 | 0.52 | 461.57 |
| 120 | 419.00 | 1.20 | 0.02 | 1.61 | 1126.17 | 0.59 | 521.98 |
| 130 | 450.00 | 1.30 | 0.02 | 1.75 | 1127.72 | 0.63 | 559.83 |
| 140 | 485.00 | 1.40 | 0.02 | 1.88 | 1129.26 | 0.68 | 602.55 |
| 150 | 529.00 | 1.50 | 0.02 | 2.02 | 1130.81 | 0.74 | 656.31 |
| 160 | 570.00 | 1.60 | 0.02 | 2.15 | 1132.37 | 0.80 | 706.21 |
| 170 | 611.00 | 1.70 | 0.02 | 2.29 | 1133.92 | 0.86 | 755.97 |
| 180 | 654.00 | 1.80 | 0.02 | 2.42 | 1135.49 | 0.92 | 808.06 |
| 190 | 693.00 | 1.90 | 0.03 | 2.55 | 1137.05 | 0.97 | 855.06 |
| 200 | 731.00 | 2.00 | 0.03 | 2.69 | 1138.62 | 1.03 | 900.71 |
| 210 | 772.00 | 2.10 | 0.03 | 2.82 | 1140.20 | 1.08 | 949.91 |
| 220 | 810.00 | 2.20 | 0.03 | 2.96 | 1141.78 | 1.14 | 995.29 |
| 230 | 840.00 | 2.30 | 0.03 | 3.09 | 1143.36 | 1.18 | 1030.72 |
| 240 | 873.00 | 2.40 | 0.03 | 3.23 | 1144.95 | 1.22 | 1069.73 |
| 250 | 906.00 | 2.50 | 0.03 | 3.36 | 1146.55 | 1.27 | 1108.62 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 260 | 940.00 | 2.60 | 0.03 | 3.50 | 1148.14 | 1.32 | 1148.62 |
| 270 | 975.00 | 2.70 | 0.04 | 3.63 | 1149.74 | 1.37 | 1189.73 |
| 280 | 1010.00 | 2.80 | 0.04 | 3.76 | 1151.35 | 1.42 | 1230.72 |
| 290 | 1040.00 | 2.90 | 0.04 | 3.90 | 1152.96 | 1.46 | 1265.51 |
| 300 | 1042.00 | 3.00 | 0.04 | 4.03 | 1154.58 | 1.46 | 1266.17 |
| 310 | 1032.00 | 3.10 | 0.04 | 4.17 | 1156.20 | 1.45 | 1252.26 |

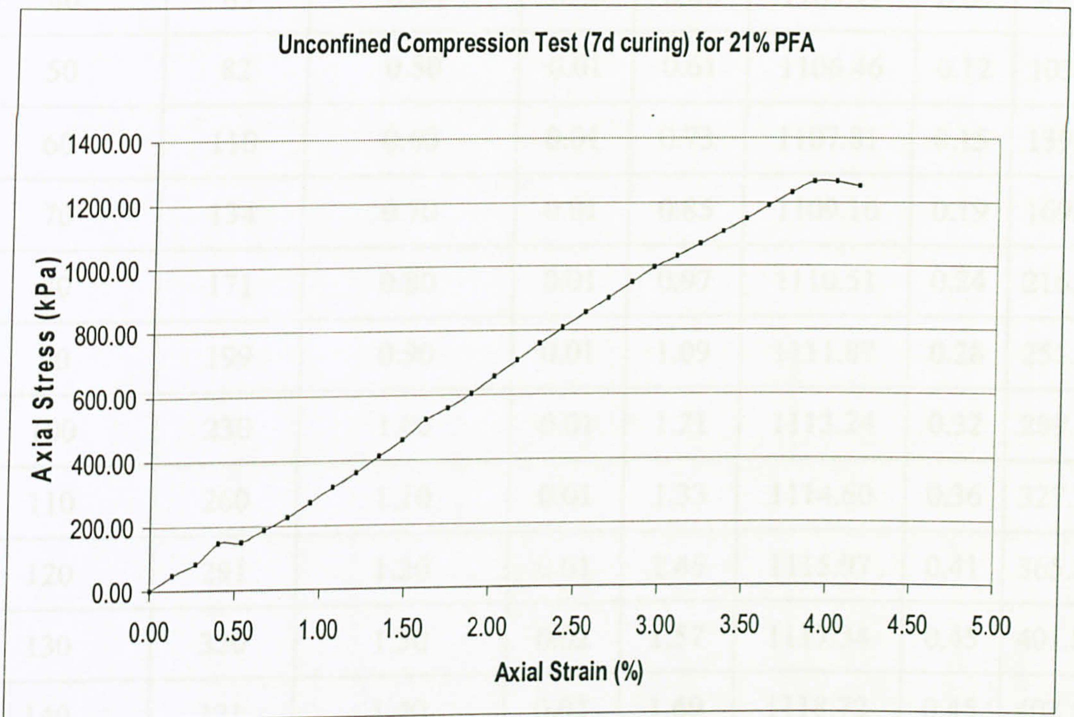



**Figure A. 37: Stress vs. Strain for 21% PFA (7 days curing)**

Table A. 50: Unconfined compression test for 24% of PFA (7 days curing)

| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL (mm) | Strain | % Strain | Corrected Area A' ($mm^2$) | Load (kN) | Stress (kPa) |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0.00 | 0.00 | 0.00 | 1099.76 | 0.00 | 0.00 |
| 10 | 21 | 0.10 | 0.00 | 0.12 | 1101.09 | 0.03 | 26.76 |
| 20 | 30 | 0.20 | 0.00 | 0.24 | 1102.43 | 0.04 | 38.18 |
| 30 | 51 | 0.30 | 0.00 | 0.36 | 1103.77 | 0.07 | 64.82 |
| 40 | 65 | 0.40 | 0.00 | 0.48 | 1105.11 | 0.09 | 82.52 |
| 50 | 82 | 0.50 | 0.01 | 0.61 | 1106.46 | 0.12 | 103.97 |
| 60 | 110 | 0.60 | 0.01 | 0.73 | 1107.81 | 0.15 | 139.31 |
| 70 | 134 | 0.70 | 0.01 | 0.85 | 1109.16 | 0.19 | 169.50 |
| 80 | 171 | 0.80 | 0.01 | 0.97 | 1110.51 | 0.24 | 216.03 |
| 90 | 199 | 0.90 | 0.01 | 1.09 | 1111.87 | 0.28 | 251.10 |
| 100 | 230 | 1.00 | 0.01 | 1.21 | 1113.24 | 0.32 | 289.86 |
| 110 | 260 | 1.10 | 0.01 | 1.33 | 1114.60 | 0.36 | 327.26 |
| 120 | 291 | 1.20 | 0.01 | 1.45 | 1115.97 | 0.41 | 365.84 |
| 130 | 320 | 1.30 | 0.02 | 1.57 | 1117.34 | 0.45 | 401.80 |
| 140 | 321 | 1.40 | 0.02 | 1.69 | 1118.72 | 0.45 | 402.56 |
| 150 | 327 | 1.50 | 0.02 | 1.82 | 1120.10 | 0.46 | 409.58 |
| 160 | 328 | 1.60 | 0.02 | 1.94 | 1121.48 | 0.46 | 410.32 |
| 170 | 345 | 1.70 | 0.02 | 2.06 | 1122.87 | 0.48 | 431.06 |
| 180 | 350 | 1.80 | 0.02 | 2.18 | 1124.26 | 0.49 | 436.77 |
| 190 | 380 | 1.90 | 0.02 | 2.30 | 1125.65 | 0.53 | 473.62 |
| 200 | 410 | 2.00 | 0.02 | 2.42 | 1127.05 | 0.58 | 510.37 |
| 210 | 440 | 2.10 | 0.03 | 2.54 | 1128.45 | 0.62 | 547.04 |
| 220 | 460 | 2.20 | 0.03 | 2.66 | 1129.85 | 0.65 | 571.19 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 230 | 490 | 2.30 | 0.03 | 2.78 | 1131.26 | 0.69 | 607.69 |
| 240 | 519 | 2.40 | 0.03 | 2.91 | 1132.67 | 0.73 | 642.85 |
| 250 | 500 | 2.50 | 0.03 | 3.03 | 1134.08 | 0.70 | 618.54 |

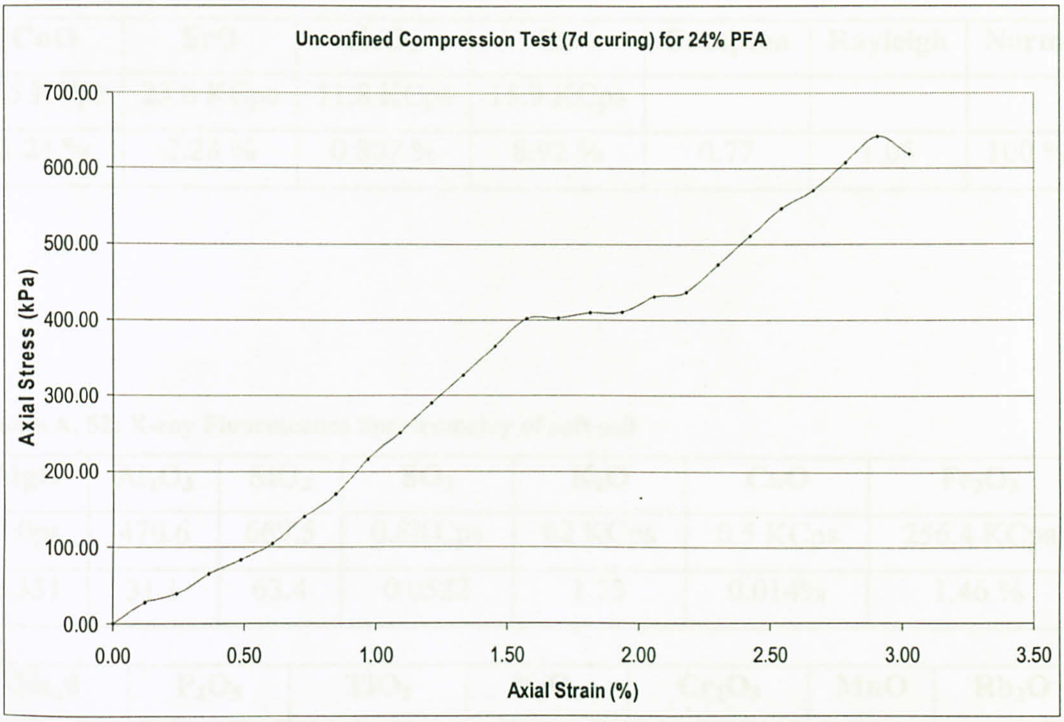


**Figure A. 38: Stress vs. Strain for 24% PFA (7 days curing)**

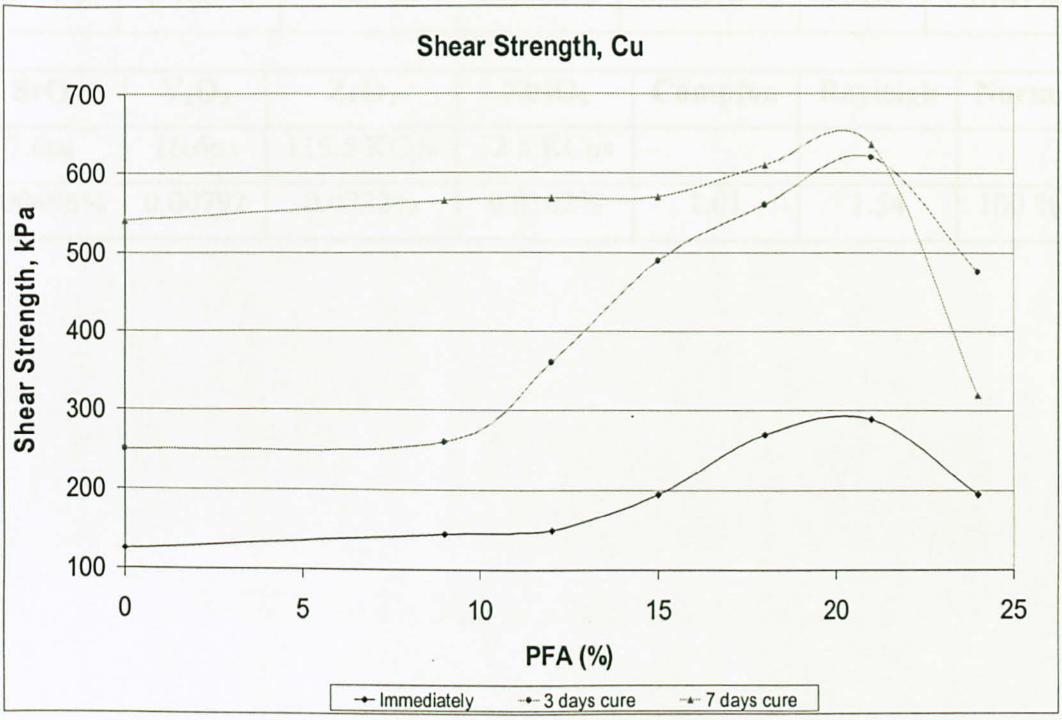


**Figure A. 39: Summary of Shear Strength, cu (kPa) for immediate, 3 and 7 days curing**

**Table A. 51: X-ray Fluorescence Spectrometry of PFA**

| MgO | $Al_2O_3$ | $SiO_2$ | $SO_3$ | $K_2O$ | CaO | $Fe_2O_3$ |
|---|---|---|---|---|---|---|
| 0.4 KCps | 1.6 KCps | 4.4 KCps | 0.5 KCps | 1.0 KCps | 5.5 KCps | 68.0 KCps |
| 2.14 % | 10.5 % | 26.5 % | 1.38 % | 1.25 % | 7.49 % | 29.7 % |

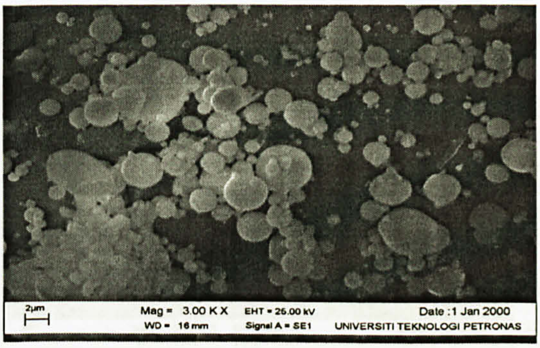
| CuO | SrO | $ZrO_2$ | Re | Compton | Rayleigh | Norm. |
|---|---|---|---|---|---|---|
| 5.5 KCps | 23.6 KCps | 11.8 KCps | 15.9 KCps | | | |
| 1.21 % | 2.28 % | 0.807 % | 8.92 % | 0.77 | 1.05 | 100 % |

**Table A. 52: X-ray Fluorescence Spectrometry of soft soil**

| MgO | $Al_2O_3$ | $SiO_2$ | $SO_3$ | $K_2O$ | CaO | $Fe_2O_3$ |
|---|---|---|---|---|---|---|
| 7.0ps | 470.6 | 669.5 | 0.8KCps | 62 KCps | 0.5 KCps | 256.4 KCps |
| 0.351 | 31.1 | 63.4 | 0.0522 | 1.73 | 0.014% | 1.46 % |

| $Na_20$ | $P_2O_5$ | $TiO_2$ | $V_2O_5$ | $Cr_2O_3$ | MnO | $Rb_2O$ |
|---|---|---|---|---|---|---|
| 0.7 KCps | 0.6 KCps | 55.4 KCps | 3.8 KCps | 1.6 KCps | 1.7ps | 22.3s |
| 0.0717 % | 0.700 % | 1.48 % | 0.0206% | 0.00578 % | 0.0107 | 0.0141% |

| SrO | $Y_2O_3$ | $ZrO_2$ | $Nb_2O_5$ | Compton | Rayleigh | Norm. |
|---|---|---|---|---|---|---|
| 7.6ps | 16.6ps | 115.5 KCps | 12.5 KCps | | | |
| 0.00496% | 0.00792 | 0.0722% | 0.0102% | 1.01 | 1.54 | 100 % |




| Element | Weight% | Atomic% |
|---|---|---|
| C | 3.09 | 5.05 |
| O | 54.92 | 67.38 |
| Mg | 1.44 | 1.16 |
| Al | 11.22 | 8.16 |
| Si | 21.11 | 14.76 |
| K | 1.75 | 0.88 |
| Ca | 2.14 | 1.05 |
| Ti | 0.56 | 0.23 |
| Fe | 3.77 | 1.32 |
| Totals | 100.00 | |

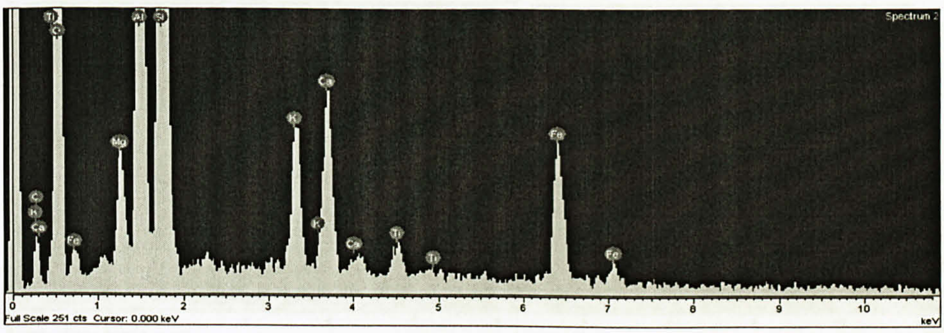
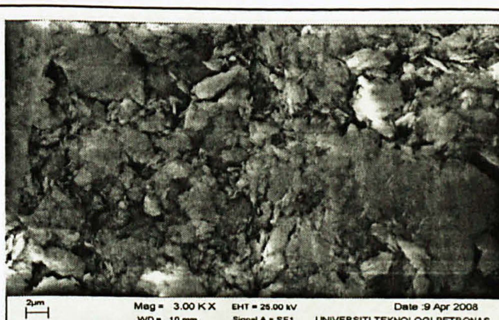



**Figure A. 40: SEM and EDX analysis for PFA**




| Element | Weight% | Atomic% |
|---|---|---|
| O | 61.22 | 73.82 |
| Al | 14.18 | 10.14 |
| Si | 21.38 | 14.68 |
| K | 1.20 | 0.59 |
| Ti | 1.17 | 0.47 |
| Fe | 0.85 | 0.29 |
| Totals | 100.00 | |

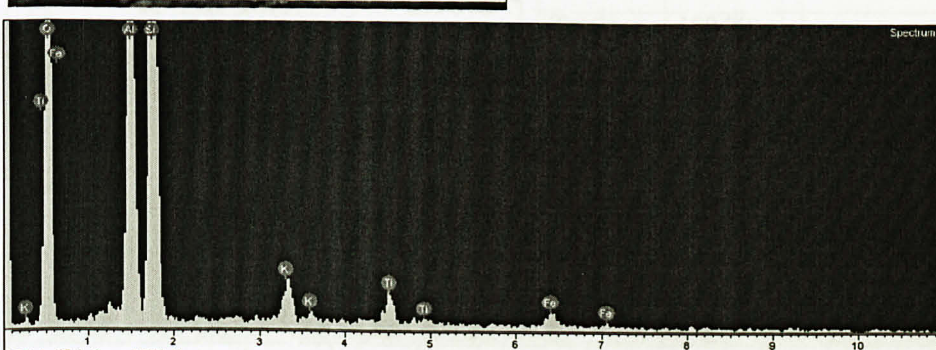
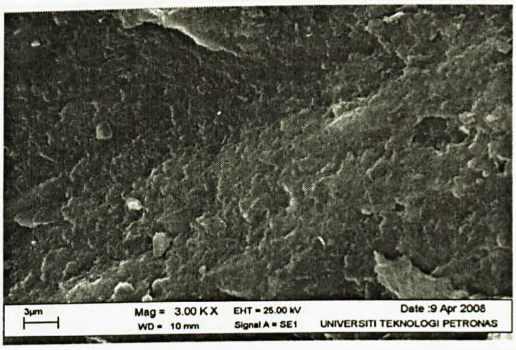



**Figure A. 41: SEM and EDX analysis for untreated soil**




| Element | Weight% | Atomic% |
|---|---|---|
| C | 2.58 | 4.18 |
| O | 63.37 | 77.22 |
| Al | 14.47 | 10.45 |
| Si | 22.12 | 15.36 |
| K | 0.93 | 0.46 |
| Ca | 0.53 | 0.26 |
| Ti | 0.40 | 0.16 |
| Fe | 0.75 | 0.26 |
| | | |
| Totals | 100.00 | |

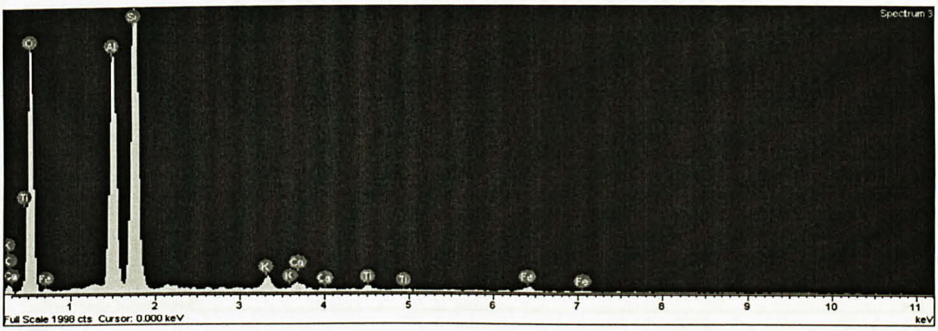
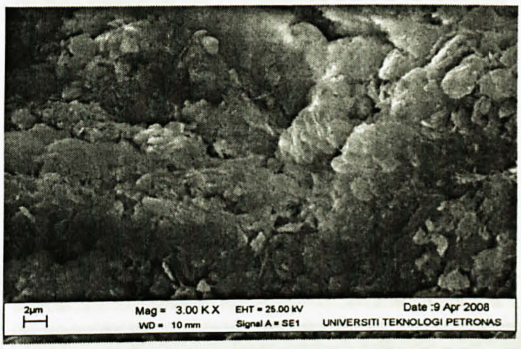



**Figure A. 42: SEM and EDX analysis for 9% of PFA (immediate test)**




| Element | Weight% | Atomic% |
|---|---|---|
| O | 61.10 | 73.70 |
| Al | 14.49 | 10.37 |
| Si | 21.26 | 14.61 |
| K | 1.35 | 0.67 |
| Ti | 0.63 | 0.25 |
| Fe | 1.17 | 0.41 |
| | | |
| Totals | 100.00 | |

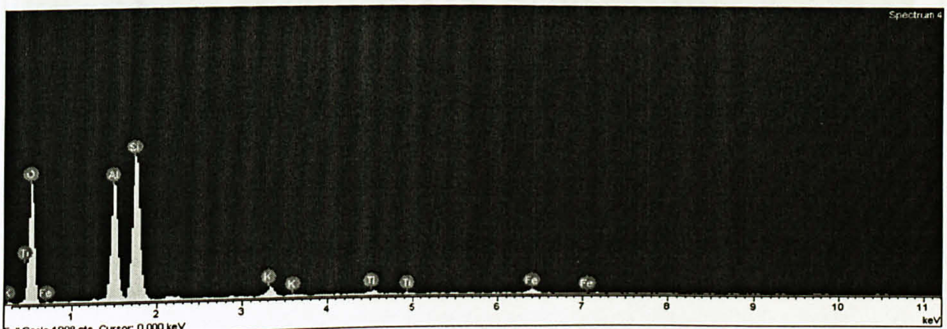
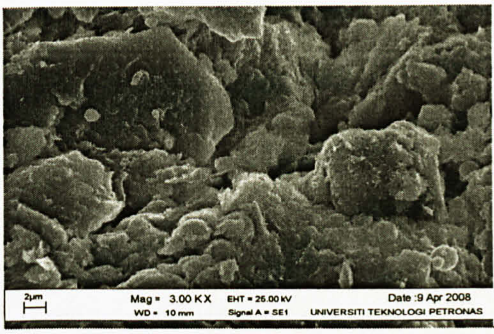



**Figure A. 43: SEM and EDX analysis for 9% of PFA (7 days curing)**




| Element | Weight% | Atomic% |
|---|---|---|
| | | |
| C | 2.45 | 3.99 |
| O | 63.46 | 77.44 |
| Mg | 0.46 | 0.37 |
| Al | 13.10 | 9.48 |
| Si | 21.81 | 15.16 |
| K | 1.02 | 0.51 |
| Ca | 0.62 | 0.30 |
| Ti | 0.48 | 0.20 |
| Fe | 1.49 | 0.52 |
| | | |
| Totals | 100.00 | |

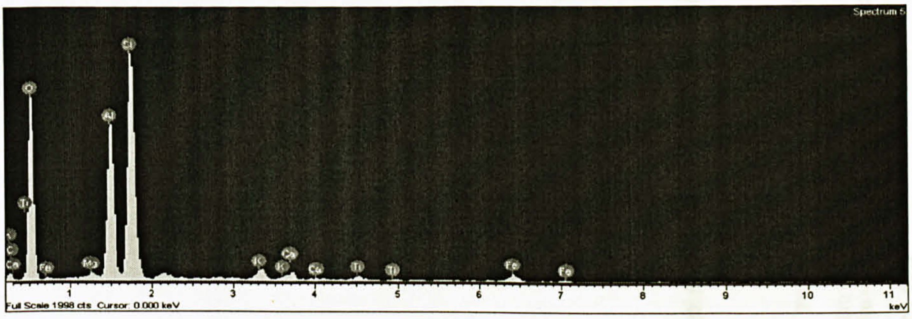
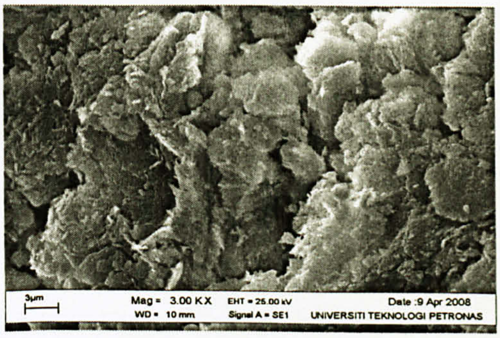



**Figure A. 44: SEM and EDX analysis for 21% of PFA (immediate test)**




| Element | Weight% | Atomic% |
|---|---|---|
| | | |
| O | 61.42 | 74.16 |
| Al | 13.19 | 9.44 |
| Si | 21.49 | 14.78 |
| K | 0.90 | 0.45 |
| Ca | 0.97 | 0.47 |
| Fe | 2.03 | 0.70 |
| | | |
| Totals | 100.00 | |

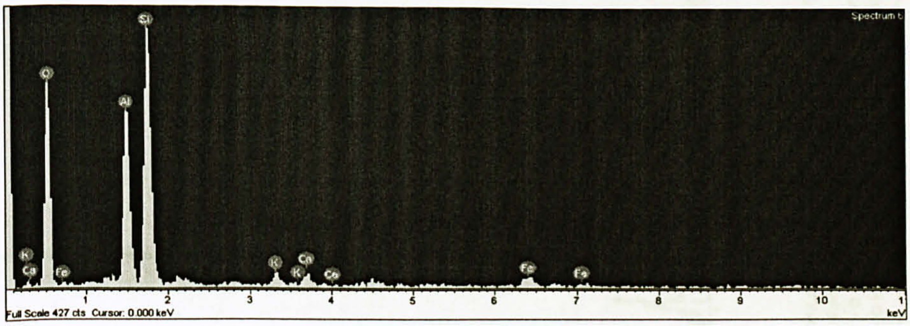



**Figure A. 45: SEM and EDX analysis for 21% of PFA (7 days curing)**

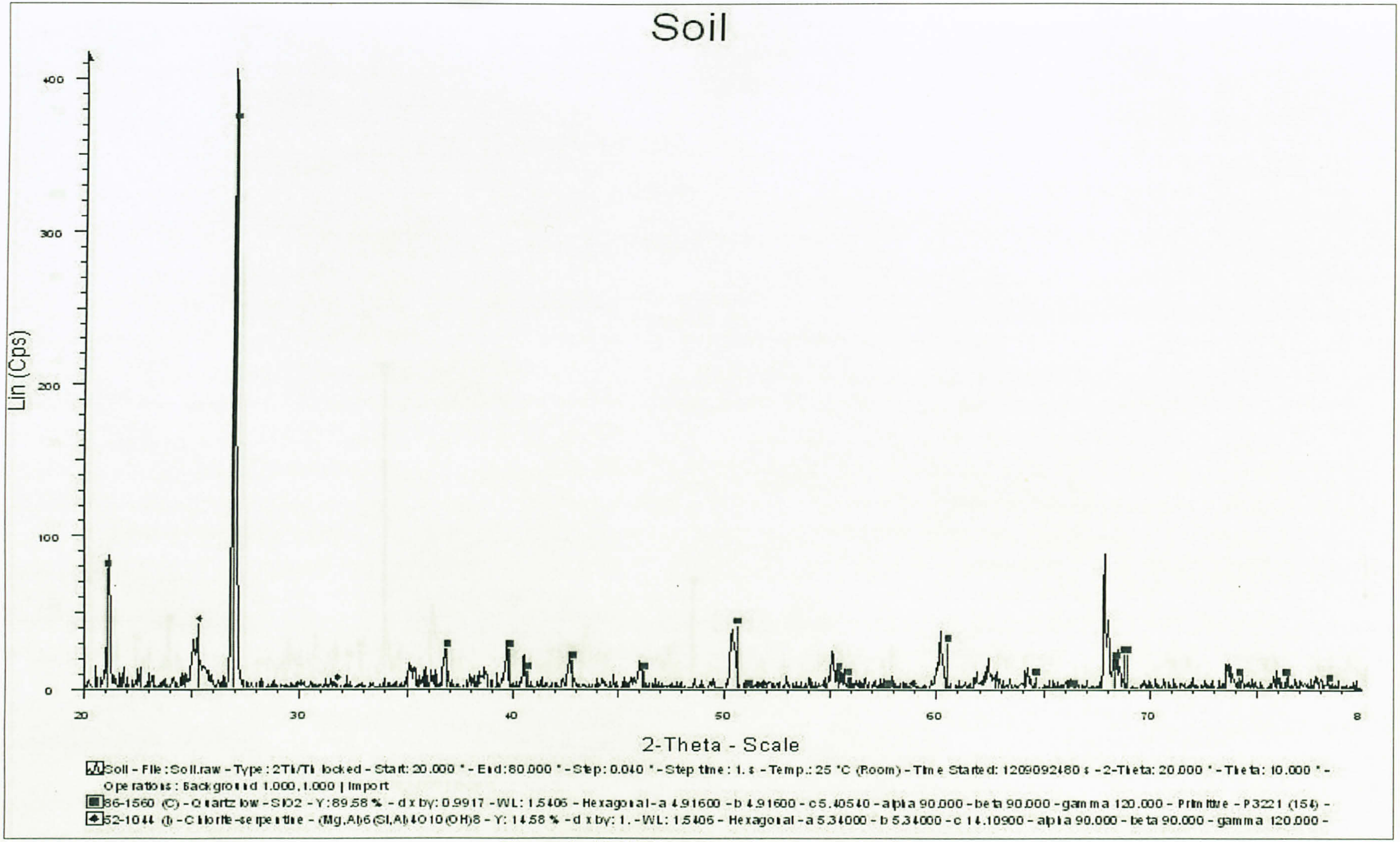



**Figure A. 46: XRD analysis for untreated soil**

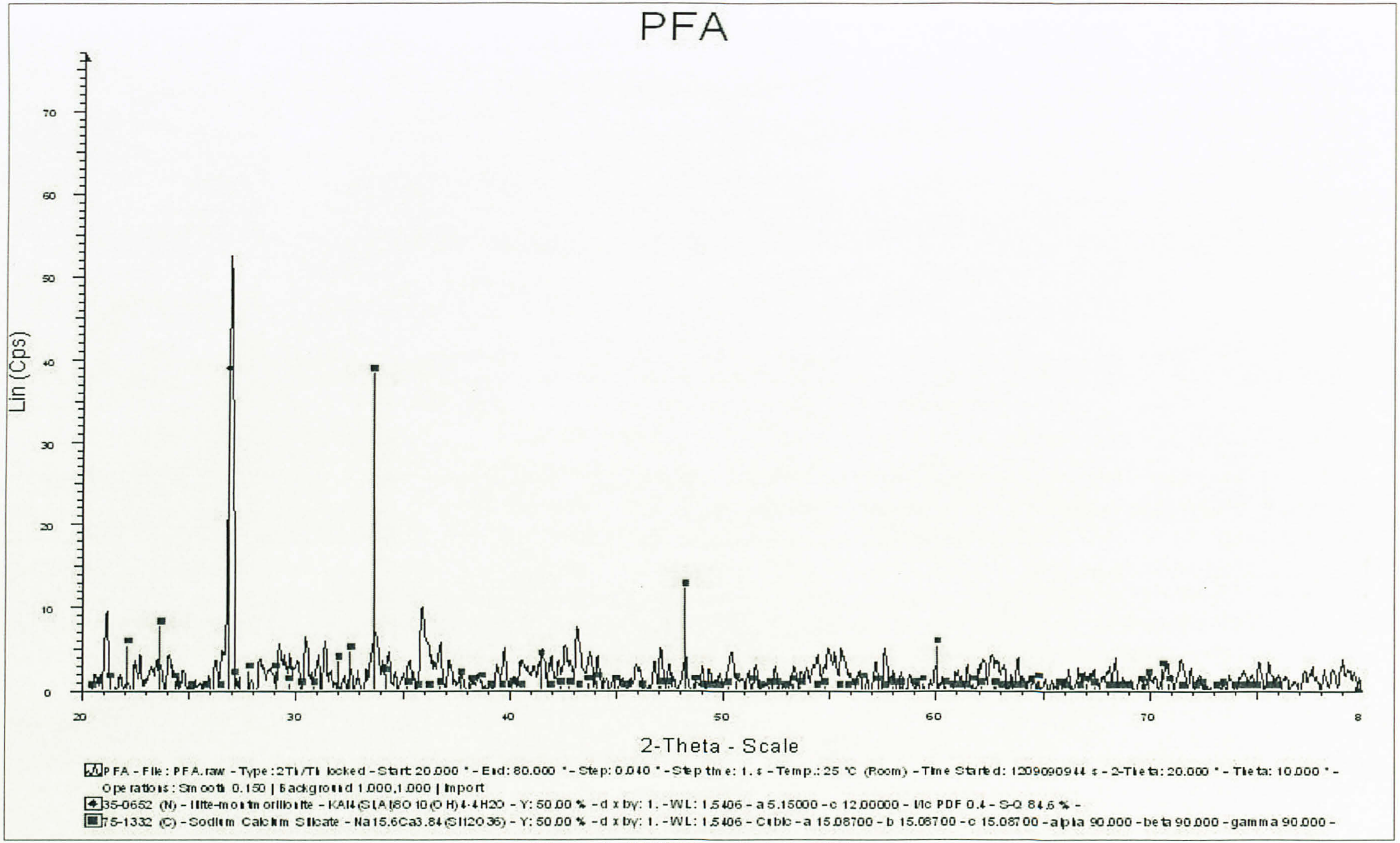



**Figure A. 47: XRD analysis for PFA**